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TRAF Software for I-405 HOV Lane Construction

EVALUATION OF THE TRAF FAMILY OF MODELS

by

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DISCLAIMER

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CHAPTER 1
INTRODUCTION

This paper discusses the application of the CORFLO model by the Washington State Department of Transportation for examining traffic congestion related to urban freeway reconstruction efforts. The model is being used to estimate congestion levels expected due to capacity restraints imposed by construction activities and to examine the impacts of alternative traffic mitigation plans on those expected congestion levels. This report documents the Department's calibration effort, the initial tests of the model's capabilities, the conclusions and recommendations that resulted from those tests, and a plan for the continuation of the research effort under this contract.

INTRODUCTION TO THE PROJECT

This report is part of a larger project investigating how the TRAF family of simulation models can be used to help determine appropriate and cost effective control strategies for nonrecurring congestion. The TRAF family consists of the following components:

- TRAF Input Processor
- Component Model (Subnetwork) Integration Processing
- Microscopic Rural Road Simulation Model (ROADSIM)
- Microscopic Arterial Simulation Model (NETSIM)
- Macroscopic Arterial Simulation Model (NETFLO Level I)
- Macroscopic Arterial Simulation Model (NETFLO Level II)
- Macroscopic Arterial Simulation Model (NETFLO Level III)
- Microscopic Freeway Simulation Model (FRESIM)
- Macroscopic Freeway Simulation Model (FREFLO)
- Equilibrium Traffic Assignment Model.

This working paper will discuss the application and evaluation of a subset of the above models that are tied together in a stand-alone package called CORFLO. The CORFLO program is a set of macroscopic simulation models for networks containing freeways and arterials. CORFLO consists of the Macroscopic Arterial Simulation Models (NETFLO Levels I and II), the Macroscopic Freeway Simulation Model (FREFLO), and the Equilibrium Traffic Assignment Model. The necessary input processor and model integration programs are also included in the stand-alone CORFLO model.

The model uses a time scan technique to simulate the flow of vehicles on the network. The model can be used in two ways. For traditional simulation, the operating parameters and volumes are put into the model, and the program calculates the delay, miles traveled, speeds, and other measures of effectiveness. The traffic assignment model can also be used in the simulation so that the model loads the network based on origin/destination data. The program thus calculates not only the measures of effectiveness but also the volumes assigned to each link in the network on the basis of the minimum travel time.

The model was developed for the Federal Highway Administration but is not yet available for public distribution. A network of arterials and freeways in the Seattle metropolitan area was used as a test case for the CORFLO model. Construction activities in this heavily traveled area were observed and data collected to determine the ability of the model to replicate the movement of traffic in the area under different scenarios.

BACKGROUND

A major issue facing traffic engineers is congestion in urban areas. There are two basic types of congestion, recurring and nonrecurring. Recurring congestion is demand that exceeds the normal capacity on a facility, causing the flow on the facility to become unstable. Nonrecurring congestion is traffic demand that exceeds the capacity of a facility because of a short-term reduction in capacity, such as a lane closure caused by construction or an incident such as a stalled vehicle or accident.

Nonrecurring congestion caused by construction activities and unexpected incidents may account for as much as 60 percent of the congestion on urban facilities. [1] Therefore, management of the impacts of construction and development of incident response plans are both major factors in the control of urban congestion because of the potentially large effect that a reduction in this type of congestion could have on the urban area without the costly additions of more roadways. Methods that can be used to minimize the effects of nonrecurring congestion are

- efficiently planned detours,
- improved traffic signal plans that deal with incident and construction congestion,
- prearranged "plans" that deal with unexpected congestion, and
- knowledge about the effects of construction on facility capacity.

However, these control strategies for nonrecurring congestion are difficult and costly to both the agency and the public to implement in a trial and error manner on the actual facilities. Therefore, the effects of different strategies must be predicted through some method of simulation. In traffic simulation, a series of calculations describe the phenomenon of traffic flow based on some theory of the behavior of traffic flow.

Simulation methods have existed for years in the form of hand calculations for highway and intersection performance, such as the equations used in the Highway Capacity Manual. [2] Computer based simulation programs, such as TRANSYT, NETSIM, and FREQ, have enhanced the speed and accuracy of such simulation. However, because the interaction of a wide variety of complex factors come into effect when simulating the interaction between arterial and freeway traffic flows, simulation models have not always worked as well as desired. Extensive testing of new models is required to ensure that the results they produce are indicative of the actual traffic conditions. This project is just such a test.

STRUCTURE OF THE PAPER

This paper is structured in four additional chapters and an appendix. Chapter 2 discusses the research approach taken thus far in the project. The network and how the model was operated for the network are described. Some methods used to simplify the network and the assumptions used in modeling the actuated signals in the network are also discussed.

Chapter 3 covers the findings of the research so far. It evaluates the model, including the calibration efforts and how the model performed in comparison with the field measurements. Chapter 4 discusses interpretation of the model results. It covers some special coding requirements that were encountered and limitations of the model that were recognized during the course of the project.

Chapter 5 contains conclusions and recommendations for further development of the CORFLO model.

The appendix describes the CORFLO model. The components of the program are discussed, along with the input and output of the different submodels within CORFLO.

CHAPTER 2
RESEARCH APPROACH

This chapter will describe the area selected for the CORFLO model application, the data needed to construct the network, how the data were collected, the use of the model, and some major assumptions used in the study.

NETWORK DESCRIPTION

The CORFLO model was applied to the network of arterials and freeways in the Seattle metropolitan area shown in Figures 2.1 and 2.2. A link-node representation of the network is shown in Figure 2.3.

General Description of Area

This area in South King County experiences daily congestion because of commuters, Longacres (a horse racing track), and major shopping areas. Congestion occurs in both the morning and afternoon peak periods, which extend from 6:30 AM until 9:00 AM and again from 3:30 PM until 6:30 PM. This area was selected as the application site because of a major construction project on I-405 that was adding high occupancy vehicle (HOV) lanes on the inside of the four-lane freeway and rebuilding the existing roadway. The construction project involved 3.0 miles of I-405 from milepost 0.00 in Tukwila to milepost 3.0 in South Renton. No lane closures were permitted on I-405 from 5 AM until 8 PM, but bridge widening and roadway widening affected other major routes such as SR 167, SR 181, and SR 900. Commuters had several alternatives to I-405, such as SR 900, Grady Way, Interurban Avenue, and other major arterials to the south of I-405. This area was also important because of its proximity to the City of Renton, which, because it already experienced daily congestion on its city streets, could not accomodate major traffic diversion through the city without substantial changes to the city's infrastructure.

The modeled area was analyzed and the alternative routes that might be affected by the construction activities were defined to include the major east/west routes from SR 18 on

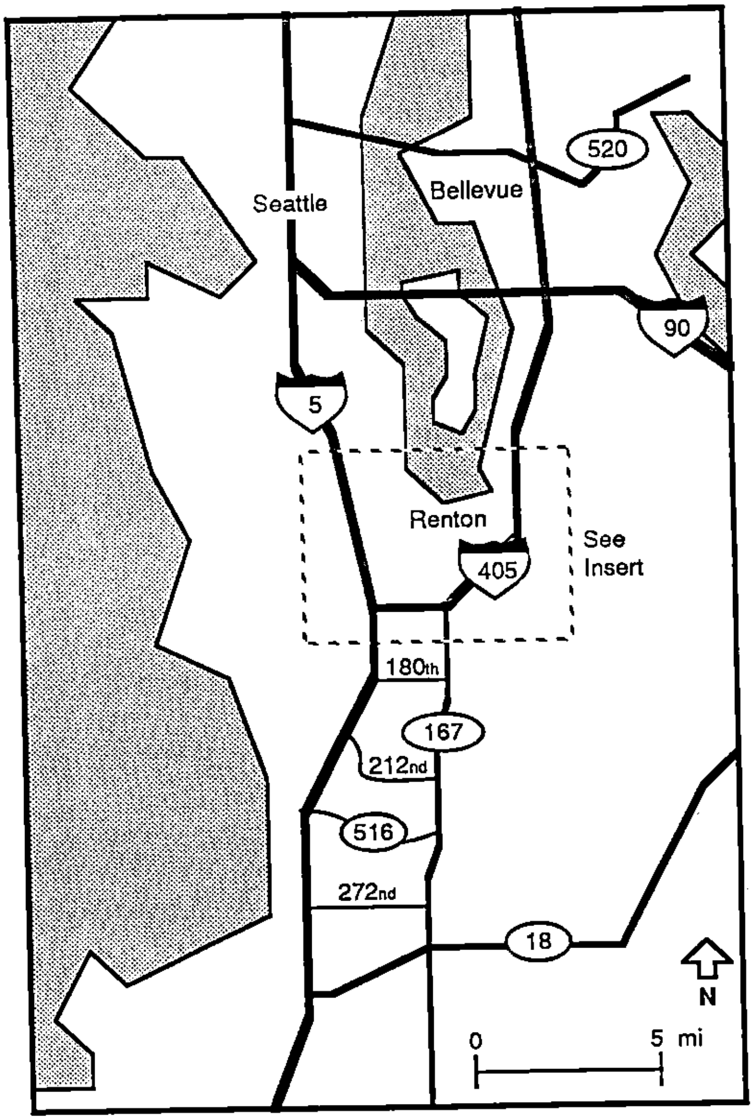
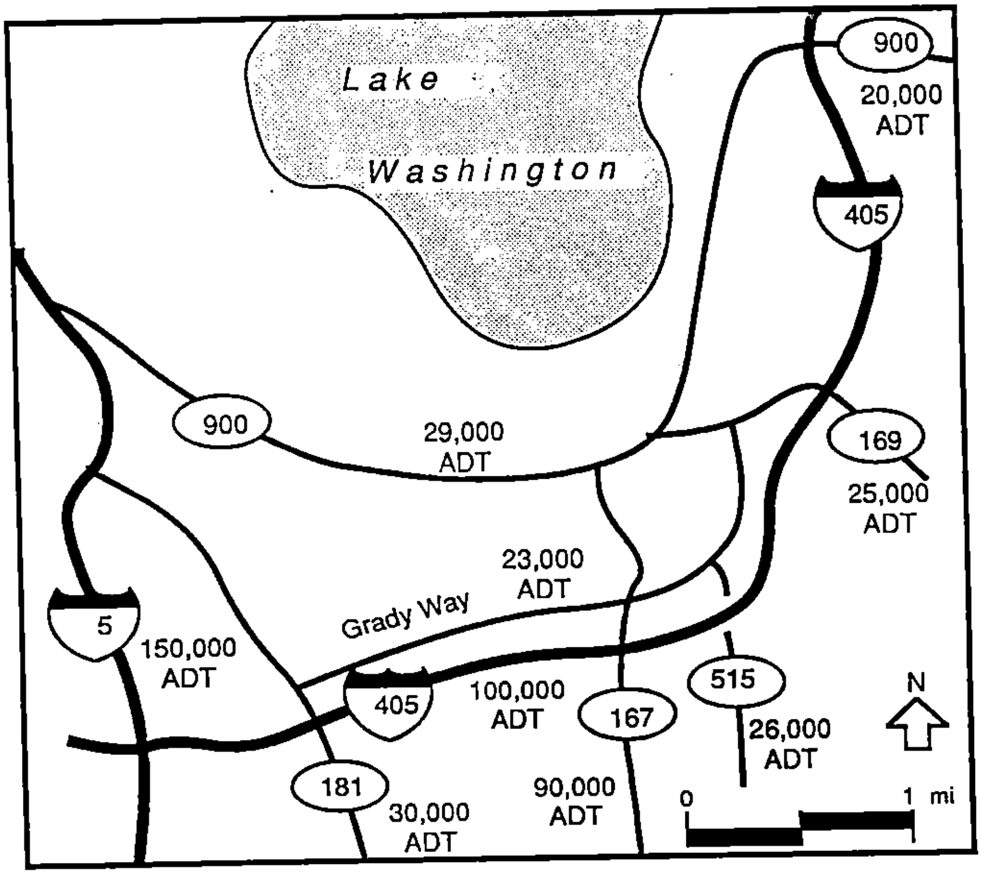


Figure 2.1. Vicinity Map



Legend
ADT = vehicles/day

Figure 2.2. Insert

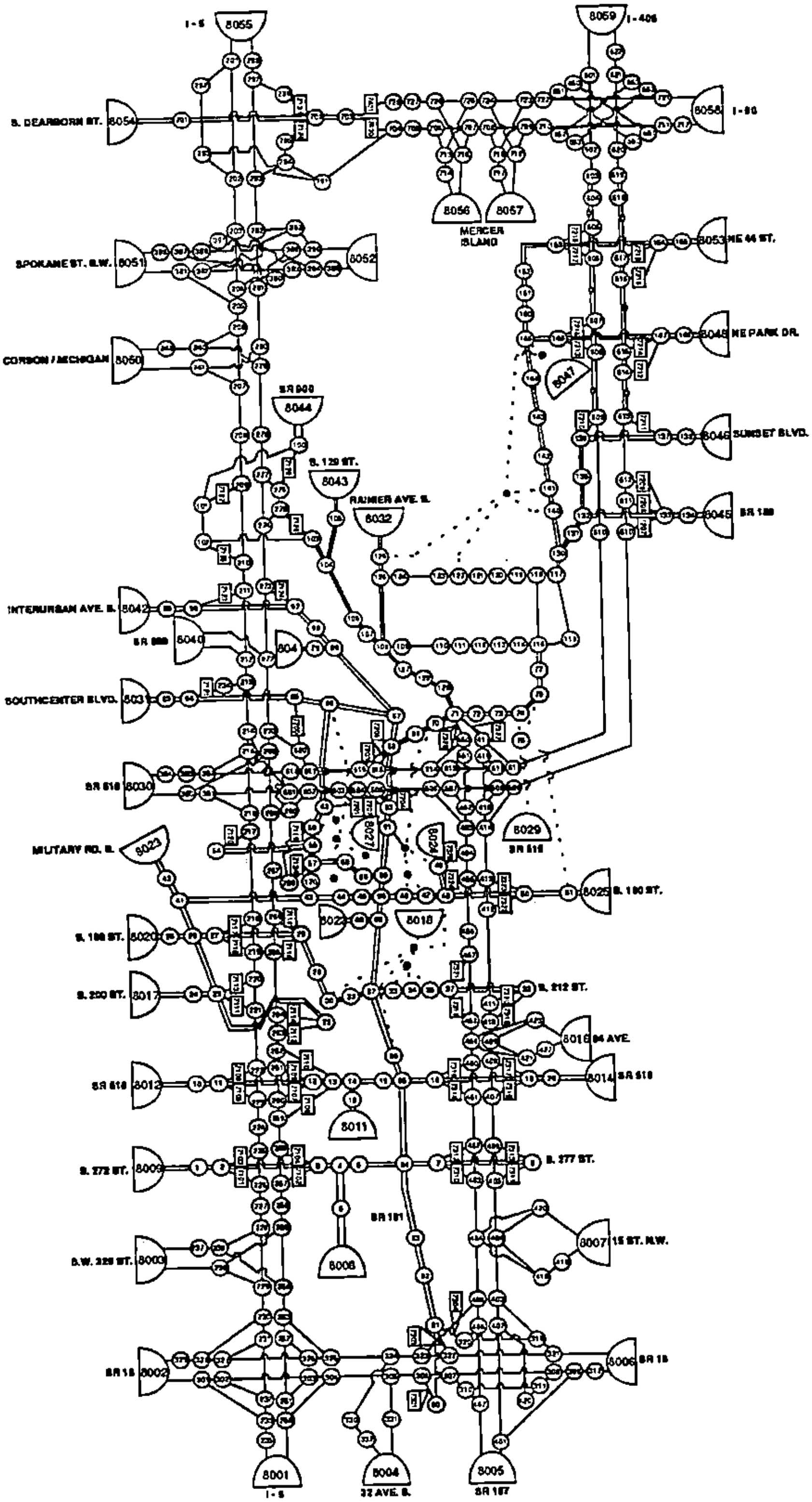


Figure 2.3 Network

the southern end of King County to I-90. The geographical area modeled was approximately 23.8 miles long in the north/south direction and 7.9 miles wide. A geographic area this large was necessary to allow inclusion of the major diversion routes for through traffic.

Links and Nodes

The network consisted of 460 directional arterial links (106.6 miles), 407 directional freeway links (146.5 miles), and 44 origins and destinations. The network required 512 nodes (242 freeway nodes, 155 arterial nodes, 71 interface nodes, and 44 origin/destination nodes) to describe the modeled area. The modeled area included the reconstruction diversion routes. Fifty uncontrolled arterial intersection nodes were used, 13 stop or yield signs, and 91 signalized arterial nodes, of which 73 had actuated or semi-actuated signal control. The network coding took approximately 560 person-hours, not including some of the time spent on data collection by the different jurisdictions.

The City of Renton has a centrally controlled Multisonics signal system for the majority of the city's arterials. Forty-seven of the signals from this system were in the project's network Eighteen of these signals were operating as actuated signals with a background cycle length to ensure arterial coordination. SR 900 is a one-way couplet through the central business district of Renton and operates on fixed-time signal settings. The remainder of the signals in the network were independent actuated traffic signals. NETFLO Level I has the ability to simulate traffic actuated signals with up to four phases. NETFLO Level II can model more than four phases, but can't simulate actuated signals. Most of the actuated signals in the network have more than four phases. To get around this problem, NETFLO Level II was selected so that the actual number of phases could be represented and fixed time settings were used to represent the "average" signal timings during the PM peak period. This will be discussed further later in this chapter.

The model requires link geometric information, signal timing information for each arterial node, and origin/destination information. This information was collected from five jurisdictions: the Washington State Department of Transportation; the cities of Renton, Tukwila, and Kent; and King County. Geometric information was gathered from each jurisdiction and supplemented by data gathered from aerial photographs and field measurements. The most difficult information to obtain was the signal timing information, which is critical to the model.

Origin/Destination Data

Origin/destination volumes were obtained from the Puget Sound Council of Governments' (PSCOG) planning information. The information was available for the year 1985 at the traffic analysis zone level. These volumes were generated with the Urban Transportation Planning System. [4] Trips were calculated in a zone by a population based multilinear function. The trips attracted to a zone were also calculated with a multilinear function based primarily on employment and retail activities. A gravity model was then employed to distribute the trips from an origin to a destination. Factors were applied to the trip table to generate trips in the PM peak period, which is three hours long. The origin/destination table used in the CORFLO model runs was one-third of the peak period trip tables provided by PSCOG. The reduced volume was necessary to model the "average" peak period hour. Other data on volumes and speeds collected in the field were collected from 4:15 to 5:15 PM. On I-405 this time period closely represented an average peak hour, as can be seen in Table 2.1. Other areas in the network experienced peak hours

Table 2.1. Comparison of Peak to Average Hourly Volume (NB I-405 @ Benson Road)

			% difference from Peak Hour
Peak Hour	(5:00 - 6:00)	3797	--
Avg. Hour in Peak Period	(3:30 - 6:30)	3755	1.1%
Hour Used in Modelling	(4:15 - 5:15)	3717	2.1%

(based on data collected June 1988)

varying from 3:15 to 4:15 PM to 5:30 to 6:30 PM. Because of the diverse peak hours, the "average" peak period hour was modeled rather than the peak hour for one portion of the network.

The traffic analysis zones that were distant from the construction area (e.g., the zones around downtown Seattle) used by PSCOG were aggregated together to reduce the coding requirements of the model. The trips from the aggregated zones were loaded at the point where most travelers from that zone would enter the network. Trips that were expected to occur on a route not modeled in the network, such as SR 99, SR 509, SR 515, and SR 520, were removed from the origin/destination table. This will be discussed further in Chapter 3.

Side streets on the major arterials were not always included in the network, since the emphasis of the research was to detect traffic diversion on alternative major arterials. The Traffic Analysis Zones were large, and origin/destination information for each side street in the zones was not available. Even though each street was not an origin/destination, the traffic signals for side streets were included to ensure that the delay a vehicle would encounter at the signal was included in the simulation. This was accomplished by modeling the green time for the side street as an all red phase for the arterial.

MODEL OPERATION

The CORFLO model was installed on the IBM 4381 mainframe computer at the University of Washington. Because the CORFLO model is a large and complex simulation package, not all of the CORFLO options and functions were used in this application of the model. The paragraphs below describe the specific aspects of the CORFLO model that were used, and how the use of those modeling components impacted the coding of input data and development of modeling assumptions.

Program Size and Testing

The CORFLO model is programmed in Fortran 77. There are 73,087 lines (5.85 megabytes) of source code. The compiled version of the program is 2.74 megabytes in the form of an executable module.

A test dataset was created, with a hypothetical network and origin/destination data, to check the functioning of the computer program on the machine once it was installed and the Fortran coding compiled. A test dataset was also received from the Federal Highway Administration to compare the output of the program installed at the University for use on this project with the output from the program at the FHWA. Both test datasets were executed satisfactorily.

Dataset Testing

When the dataset for this project was assembled, the data had to be checked for errors through the CORFLO preprocessor. The tests of the dataset were run during the day without any simulation. Each time the dataset was modified, the preprocessor was run to check for errors in the data before the simulation was submitted. The simulation runs required more computer run time and thus were run at night, since off-peak runs were free on the University's computer system. The network data were input to a series of files constructed on a microcomputer file editor and then uploaded to the mainframe. This helped keep the cost of using the mainframe computer at a minimum.

Submodels Used in Simulation

The macroscopic freeway model, FREFLO, the macroscopic arterial model, NETFLO Level II, and the traffic assignment model were used in the simulation for this project. NETFLO Level I was not used since no advantage was perceived in the extra detail that NETFLO Level I provides for arterial simulation. The downtown Renton area was most critical in terms of detail, and many of the signals were fixed time rather than actuated. The major advantage in using NETFLO Level I would have been that the model can simulate an actuated controller. However, NETFLO Level I can only assign four phases for an actuated signal, and for the majority of actuated signals in the network this would not have been enough. Also, the side streets would have to have been included in the network and an origin/destination table created for each side-street. These steps were not reasonable given available data and resources.

Actuated Signal Conversion to Fixed Time

The traffic signal timings for actuated controllers were converted to an "average," fixed time setting for the hour of 4:15 to 5:15 PM. To make this conversion, the most recent traffic volume counts were obtained for each intersection, including the turning movements, and the SOAP-84 model was used to simulate the actuated controller for that hour's volume. The signal timing plan for each intersection was used to input the phase operation, cycle lengths, and headway values used in SOAP-84.

Three major intersections in the network were used to compare the settings produced by SOAP-84 and the observed phase lengths in the field. The intersection of SR 181 and 180th Street SW was observed during the afternoon peak period hour of 4:15 to 5:15. The average cycle length for this signal was calculated to be 196 seconds. The results of a SOAP simulation calculated the cycle length to be 205 seconds. The simulation of the actuated signal was considered good for this intersection. The resulting simulation for two other major intersections, Interurban Avenue at Southcenter Boulevard and Interurban Avenue at Grady Way required, further analysis. Again, the intersections were observed from 4:15 to 5:15 and the average phase durations were calculated. Manual turning movement counts were also conducted at the same time. The SOAP simulation resulted in much shorter cycle lengths for these two intersections, as shown in Table 2.2. The phase durations produced by the SOAP simulation were all significantly lower than the observed phase durations.

In order to replicate the functioning of an actuated controller with fixed signal plans, SOAP uses a mathematical function based on the degree of saturation occurring at that

Table 2.2. Comparison of SOAP vs. Actual Cycle Length for Signals with Long Gap Outs

Intersection	Measured	Cycle Length SOAP-84 Sat 95%	80%	70%
Interurban Ave @ S. Center Blvd.	174	68	97	160
Interurban Ave. @ Grady Way	170	78	265	--

intersection. SOAP's default degree of saturation is 95 percent, which is the value attempted by a well timed signal. A signal with a high "gap out," such as 4 seconds, will result in a lower degree of saturation than is expected in a well timed intersection. A detailed examination of the signal timing information for the two problem intersections revealed that the timing was set for a "gap out" of 4 or 5 seconds. Therefore, the project team used a degree of saturation of between 70 and 85 percent to more closely replicate the actual signal phase operation of these intersections.

By using a lower degree of saturation, the project team was able to develop timing plans with the SOAP84 model which correlated well with the actual operation of the tested signals. Other than the adjustment of the O/D information to fit the CORFLO network and modeling time frame, this was the only major adjustment of input data that was done prior to the initial calibration efforts with the model.

CHAPTER 3
FINDINGS

This chapter reviews the calibration of the model results from the simulation of the construction activities. It describes the comparison of the model results against volumes and speeds collected from the operation of the facilities being modeled. It also describes the efforts made to calibrate the model in terms of required network coding changes and manipulation of the original input datasets.

CALIBRATION OF THE MODEL

After the input data were collected for the network, CORFLO was run and the volumes and speeds on the simulated network where compared to those measured on the real facilities. A volume simulated within 10 percent of the actual volume was considered calibrated. This criterion was established as an acceptable level at which simulation would reasonably reflect the actual conditions, which vary from day to day.

The process of calibrating the model to match actual volumes involved three steps.

1. Adjust the Origin/Destination Matrix. Trips that were taken on routes not modeled in the network were removed from the O/D table.
2. Adjust Access to the Arterial Network. Entry points onto the network from the zones were adjusted to distribute the load of traffic to or from a particular origin/destination to several points on the network. This was done through the use of artificial links and nodes that did not represent actual streets and through the manipulation of signal timings at the entry point intersections. The artificial links were used at five locations in the "heart" of the network. In these areas the origin/destination zone covered several streets within the geographic area of interest, and the trips could not be assigned to one particular entry or exit point in the network without critically overloading those links.

3. <u>Adjust the Freeway Links (Refine the network)</u>. The final step was to adjust the capacity of certain links on the freeways and to adjust the length and speed of entry links for freeways.

These changes are described in more detail below.

Adjusting the Origin/Destination Matrix

The calibration process was begun with the full origin/destination table produced by the PSCOG. Trips from distant zones were aggregated for the zone structure used in this project. The trips from the full PM peak tables were divided by three to represent the average hour during the peak period. Trips that could take paths not included in the modeled network were initially left in the O/D table. Trips were loaded onto the network at one location for each zone or group of zones. These loading points were the entry/exit links to and from the network.

The result of this first run was that in the portions of the network of most interest (near the construction project), the traffic assignment model overassigned trips to roadways. Trips were overassigned by as much as 275 percent from the actual volumes on the facilities and well beyond the capacity of many of the roadways, especially the freeway links. However, the simulation results showed lower volumes traveling on the links than actually existed on the facilities. This problem was perceived to be caused by a large amount of "spillback" on the arterial links. Spillback was not defined in the documentation but was assumed to mean an excess of vehicles queuing on a link and spilling upstream into the previous link. This occurred most noticeably at the entry points on the arterial portion of the network and at the adjacent intersections. Essentially, the simulation model found large bottlenecks upstream of the area of interest that prevented sufficient numbers of vehicles from reaching those intersections of the network.

The researchers concluded that the origin/destination table contained too many trips, so the trip table was factored by 90 percent, 75 percent, and 50 percent to reduce the spillback problem. These calibration runs did not dramatically improve the spillback and resulted in assignments lower than actual volumes in portions of the network. Spillback was occurring because the trips from each zone were being loaded at one point, rather than being spread among multiple points, as really occurs. The traffic signals controlling these entry points could not allow that volume of vehicles through the intersection during the simulation. It was also apparent that trips that could take other routes were greatly affecting the calibration, since the network was operating at or beyond capacity in the areas around the construction and on I-5.

Trips that could (and logically would) take alternative routes between adjacent zones, such as between the Spokane Street area (West Seattle) and the SR 518 area (Sea-Tac Airport) were removed. Many of the trips between these zones could be taken on SR 99, SR 509, 1st Ave. South and other routes not included in the modeled network. The trip table was modified so that the number of vehicles entering the freeway from these external zones would match the Washington State Department of Transportation 1986 ramp data. [5] No trips that would cross the network or in zones considered internal to the network were removed. Only trips between zones on the external parts of the network were removed, for example between zones represented by nodes 8040 and 8042, shown in Figure 2.3.

After these changes were made to the O/D table, the assignment of trips to the network, and especially to the freeways, improved significantly. However, the simulated volumes were still significantly lower than the actual volumes.

Adjusting Access to the Arterial Network

The researchers decided at this point that the signal timing information could be ignored at entry/exit points in the outlying areas of the network, the intersections at nodes numbered 11 and 23 in Figure 2.3. The delay from the signals at these intersections was not important in determining the diversion of vehicles caused by construction activities.

Spillback was a major reason that the simulated volumes were lower than the assigned volumes. This was because the trips were trapped in the spillback and were not getting onto the network. The most severe spillback was occurring in the internal zones of the network. Artificial links were then added in these zones to allow multiple access points to and from the network (i.e., those zones nearest the construction area). The nodes connecting these artificial links were coded as uncontrolled intersections so that all approaches would have free flowing conditions. The length and capacity of these artificial links were varied to influence the distribution of these trips. It was difficult to determine at what geographic points to load the trips onto the network. Five of the PSCOG traffic analysis zones in the middle of the network had multiple access points, and within several of these zones there were different land uses. Figure 3.1 shows the traffic analysis the zone for the Renton City area. This zone contained residential, commercial, and industrial areas, as well as a few special areas such as the airport and the school. These different types of land use generated different numbers of trips at different times of the day. The difficulty arose in knowing where to load the trips from this zone onto the network and where to allow the trips destined for this zone to exit the network, as these would both change with the time of day. Figure 3.2 shows the final configuration of streets and artificial links that were created for this zone.

The artificial links did successfully disperse the trips and eliminate the spillback in three of the five zones. Several more attempts were made to distribute the remaining congested trips and influence where those trips were loaded onto the network.

Adjusting Freeway Links (Refining the Network)

At this point the calibration efforts turned to the freeway entry points to clear the unrealistic congestion that was preventing trips from getting onto the freeway. The model did not flag the congestion on freeway links as it did in identifying spillback on arterial links. Apparently, congestion was hampering vehicles from getting onto the network through the freeway links, and those vehicles that did enter the freeway did so with speeds of 0.1 to 1.0 mph. The origin/destination table was further revised to eliminate some of

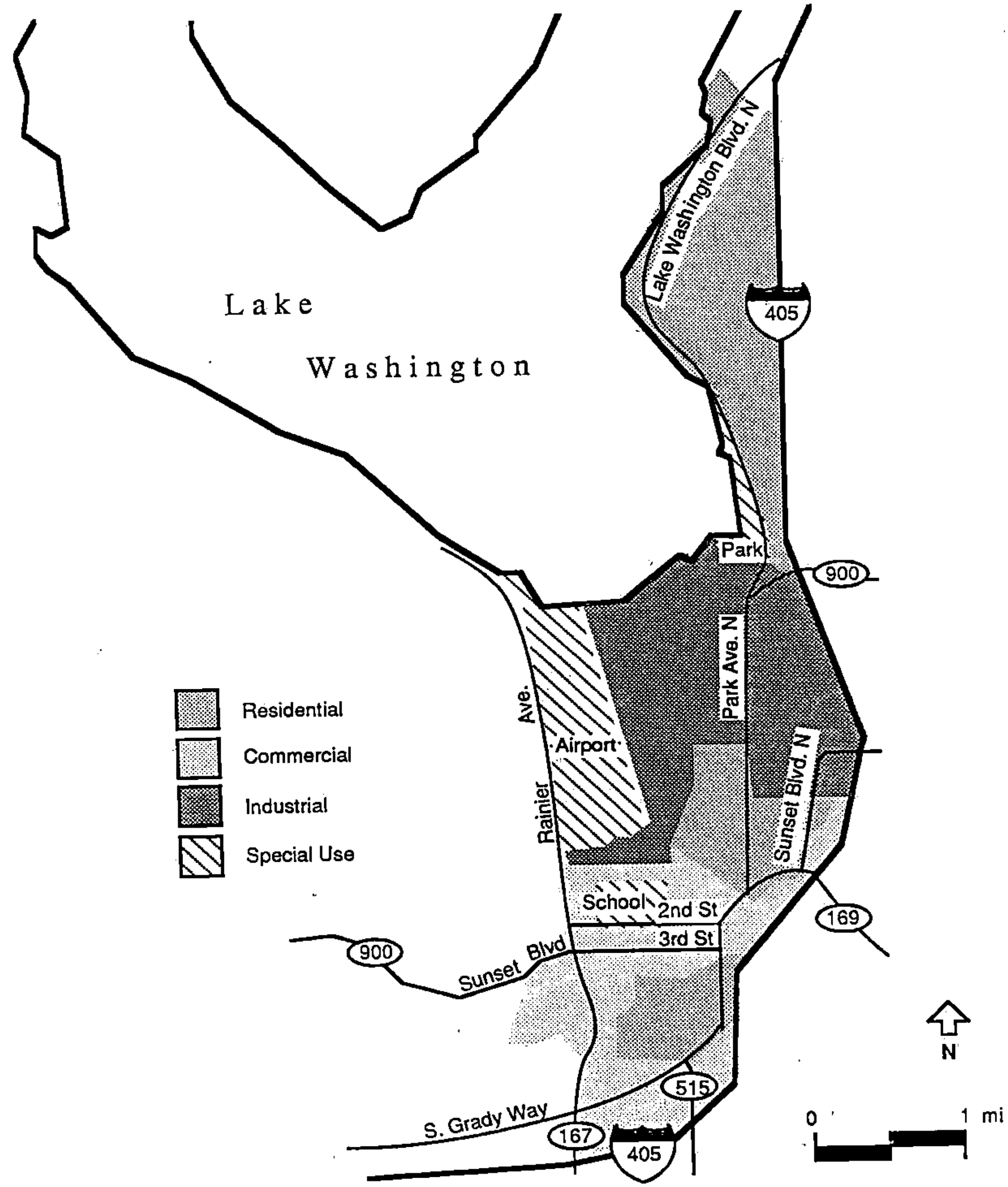


Figure 3.1. Land Use Pattern in Renton

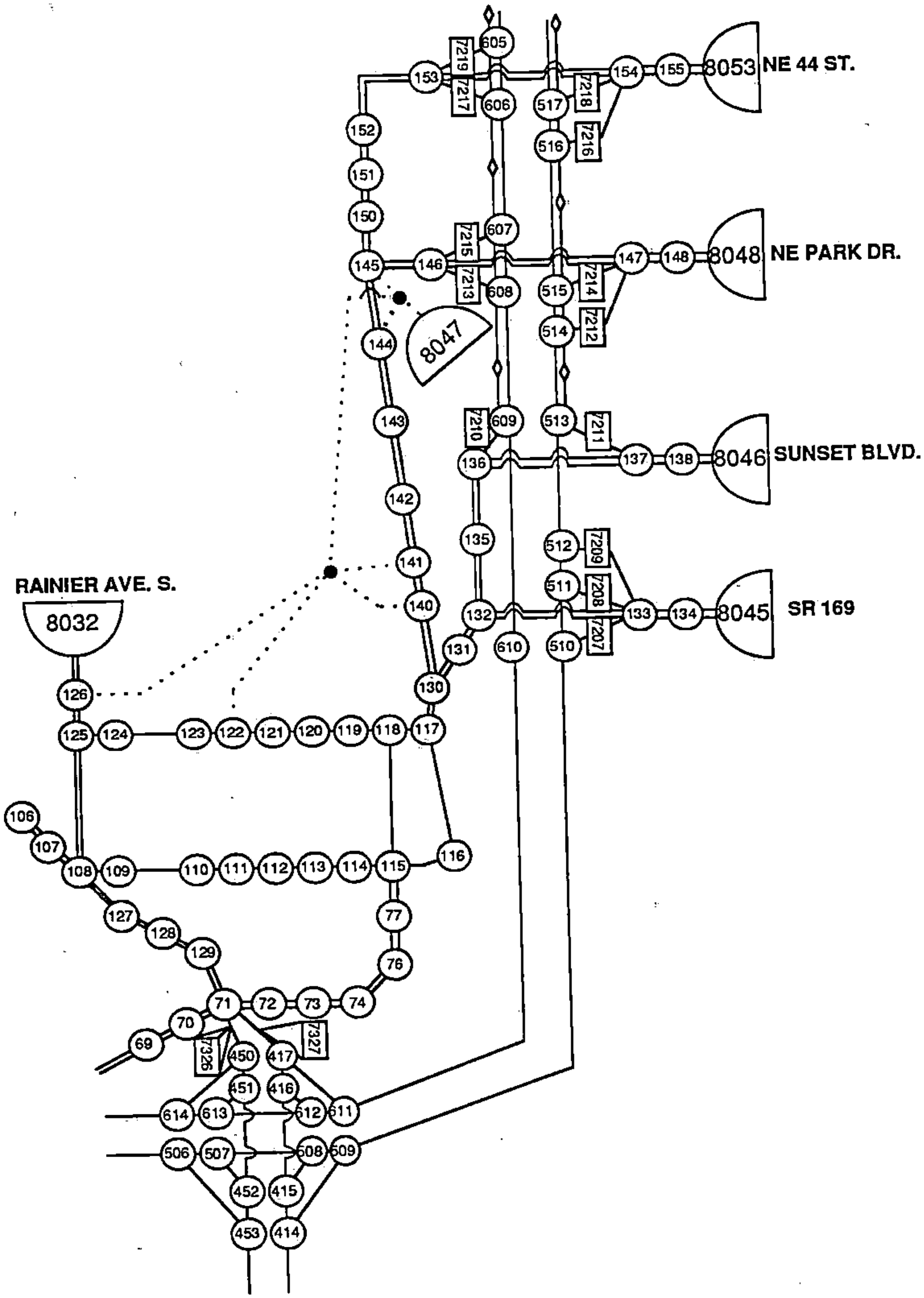


Figure 3.2. Renton Network

this congestion, while the correct number of vehicles entering at the on-ramps was still maintained.

The speeds that were being modeled at these entry points onto the freeway seemed to be unreasonably low. The unusually low speeds appeared to be related to the short distance (100 feet) assigned to these entry points. The distance of 100 feet was arbitrarily set and had no bearing on the actual network, so the entry links were changed to 200 feet. This appeared to make the simulation more realistic, allowing speeds near 10 mph when volumes approached the capacity of the link. The unrealistically low speeds, however, brought into question the freeway off-ramp lengths, which also were originally set to 100 feet.

The decision was made, while the network was coded, that off-ramps would be modeled primarily as arterial links and on-ramps would be modeled as freeway links. The logic for this decision is that the point on the roadway that would control the flow of vehicles should be the type of link being modeled. For an off-ramp, the point of traffic control is the stop sign or traffic signal at the end of the ramp; thus the ramp should be modeled as an arterial. Using the same logic, the on-ramps should be modeled as freeway links since the flow on the freeway is the control point for the ramp.

A test dataset was created that had off-ramp freeway links, each with a capacity of 2,000 vehicles per hour (vph) but different lengths ranging from 100 feet to 1,000 feet. An origin/destination table was created to assign 2,000 vph to each off-ramp so that the ramp would be operating at capacity. The result of the test network showed that the distance of 100 feet was too short and caused unrealistic speeds and volumes to be simulated, as shown in Table 3.1.

The interesting result of these test freeway off-ramps was that they all had the same capacity and volume assigned to them, yet the speed for the 800 foot and the 1,000 foot ramps decreased from 53.3 mph to 43.7 mph for no apparent reason. There was no capacity restraint beyond the link, since the vehicles then exited the network, so the reason

Table 3.1 **Results of Test Freeway Ramps**

Ramp Length	Simulated Speed	Simulated Volume
100 feet	18.9 mph	1876
200	53.2	1998
400	53.3	1998
600	53.4	1980
800	43.7	2006
1000	43.7	1997

for the slowdown in speed was not apparent. No reason for this difference in speed was discovered in the documentation or in further tests of freeway sections. The freeway portion of off-ramps was then changed to 200 feet to alleviate the apparent error in modeling ramps with a length of 100 feet.

The network was refined once again in the calibration stage to more closely match the volumes measured on the roadway. This refinement was intended to increase the capacity of certain freeway links on I-5 so that more vehicles could enter the network. These links were at entry points that were experiencing very low speeds (less than 5 mph) and operating at capacity. The increased capacity resulted in more vehicles simulated through the links, which brought the volumes on I-5 closer to the measured volumes.

Ramp Jumpers

A disturbing aspect of ramp and freeway congestion was observed on some freeway ramps. In these cases, vehicles exited the freeway on a ramp, crossed through the intersection at the ramp signal and re-entered the freeway in their original direction on the other side of the interchange. While this "ramp jumping" phenomenon actually occurs occasionally, real ramp-jumping does not occur in the places and circumstances predicted by the model.

In many cases, the model predicted the ramp jumping to occur despite freeway speeds in excess of 35 mph, while ramp speed had degraded to as low as 0.1 mph. Under these circumstances, travelers were paying a time penalty to perform the "ramp jump."

This unrealistic action is likely the result of either limitations in the traffic assignment model, or limitations in the interaction of the traffic assignment and traffic simulation models.

In order to eliminate this traffic pattern and provide more realistic ramp flows, the ramp intersections were recoded to eliminate the straight "off ramp to on ramp" movement used by "ramp jumpers." This alleviated the immediate problem of overly congested ramps, but it could not solve the programing logic problems that created the problem in the first place.

Speed Comparison

The average speed of real vehicles traveling through a section was collected and compared with the model output as a measure of the model's ability to simulate the existing conditions. Travel times were collected in the field using a license plate matching method.. Travel times were collected on I-405 for the northbound and southbound directions in the construction zone and northbound on SR 167. Travel times were then converted to an average speed over the section of highway. Table 3.2 compares the simulated speed and the measured speed.

The simulation on the freeways was accomplished with the speed/density relationship discussed in the appendix. As the volume, thus the density, decreased, the speed increased. The simulated speed on I-405 was twice the measured speed. This could have been caused, in part, by the lower than measured volumes that the model simulated.

Table 3.2. Model Calibration Speed Comparisons

Route/Direction	Measured Speed	Modeled Speed
I-405 SB	28.5 mph	53.8 mph
I-405 NB	21.9 mph	43.3 mph
SR 167 NB	53.1 mph	53.0 mph

The speed on SR 167 was the same as the simulated speed for the days it was measured. The speed did vary on SR 167, depending on the conditions on I-405. Because the measured speed varied substantially from day to day on SR 167, conclusions could not be reached concerning the speeds simulated by the model. Other locations, such as I-90, had speeds similar to what was regularly observed in the field.

Results of Calibration

The calibration efforts resulted simulated volumes similar to the measured volumes on many of the freeways and some of the arterials close to the construction activities. The area of most interest was the I-405 and Renton vicinity where the construction activity was, so the volumes in this area were most closely compared. Volumes on the alternative routes were checked for reasonableness; however, not a lot of effort was spent in trying to match the volumes on the roadways that were some distance from the construction activity. Table 3.3 shows the comparison of selected locations on the different routes.

The route most poorly modeled was SR 181. This arterial was considered to be one of the critical routes for traffic diversion, and yet efforts to more closely match the volumes on this street did not improve the calibration of the route.

Nineteen calibration runs were made. None of the runs modeled volumes on all of the critical routes within 10 percent. In most runs, the routes not matching volumes within 10 percent were 272nd Street, SR 516, 212th Street, and the locations shown in Table 3.3. The diversion routes south of 180th Street were not really operating at capacity, so matching the volumes within 10 percent was not considered important as long as the travel time on these routes was realistic. These routes were simulated at free flow speed so the travel time would be correct.

The researchers could not determine whether the difficulty in calibrating the model was due to the traffic assignment model, the simulation model, or a combination of the two. However, clearly there were problems with the traffic assignment. The traffic

Table 3.3. Model Calibration Volume Comparisons

Route	Link	Measured Volume	Simulated Volume	% Different
180th St.	45 89 EB	1220	1140	7
	46 89 WB	1130	899	20
Strander	59 90 EB	1100	815	26
	90 59 WB	840	444	47
SR 181	93 68 NB	1220	835	32
	68 93 SB	1010	309	69
SR 900	103 104 EB	980	986	1
	104 103 WB	850	486	43
	104 106 EB	1230	1487	21
	106 104 WB	760	637	16
S. 2nd St.	122 123 WB	1000	611	39
S. 3rd St.	112 113 EB	1100	746	32
I-5	266 267 NB	4680	4259	9
	217 218 SB	7610	7888	4
	271 272 NB	6010	5347	11
	212 213 SB	8600	8621	0
	280 281 NB	6830	4898	28
	205 206 SB	6460	7778	20
I-405	505 506 NB	3700	3356	9
	614 615 SB	3580	2962	17
	509 510 NB	3920	3678	6
	610 611 SB	3320	2949	11
I-90	704 705 EB	5070	3938	22
	727 728 WB	1460	1406	4
SR 167	413 414 NB	2240	2231	0
	453 454 SB	3130	2679	14

assignment model severely underloaded SR 181. Since efforts on 19 calibration runs were unable to resolve the assignment problem, the research team decided to discontinue calibration attempts and model a construction activity.

MODELING CONSTRUCTION ACTIVITIES

This portion of the study was intended to test the model's ability to simulate a variety of construction activities that would affect travel through the construction area. This was not realized because the contractor did not follow the original construction schedule, and no closures of I-405 were allowed from 5:00 AM to 8:00 PM. The only closure of lanes that occurred during the peak hours was on SR 167 at I-405 during the reconstruction of the I-405 overcrossing and on SR 900. Data were collected on traffic before and during the SR-167 closure, and the model was used to duplicate the capacity restrictions of that construction effort.

The construction activities at the I-405 bridge over SR-167 required the closure of one lane in each direction on SR 167. This closure continued from May through October 1988. Figure 3.3 is a diagram of the interchange with the lanes closed. Travel time data were collected for the northbound traffic on SR 167 for three days beginning on May 17, 1988, from 4:15 to 5:15 PM. Volume information was gathered at the five locations shown in Figure 3.3 for two weeks from May 16 through May 27, 1988.

The situation was modeled with the reduced capacity on the links with lane closures, and the speeds and volumes were compared to the results of the simulation without the lane closures. Figure 3.4 shows the results of the simulation with and without the lane closures. The simulation showed essentially no change in the volume or speed of vehicles in the immediate area of these lane closures. This reflected what actually occurred in the field. Even though this is a heavily traveled area with daily congestion, the congestion northbound is a result of traffic traveling north on SR 167 and then north on I-405. The closure northbound on SR 167 occurred downstream of the ramp to

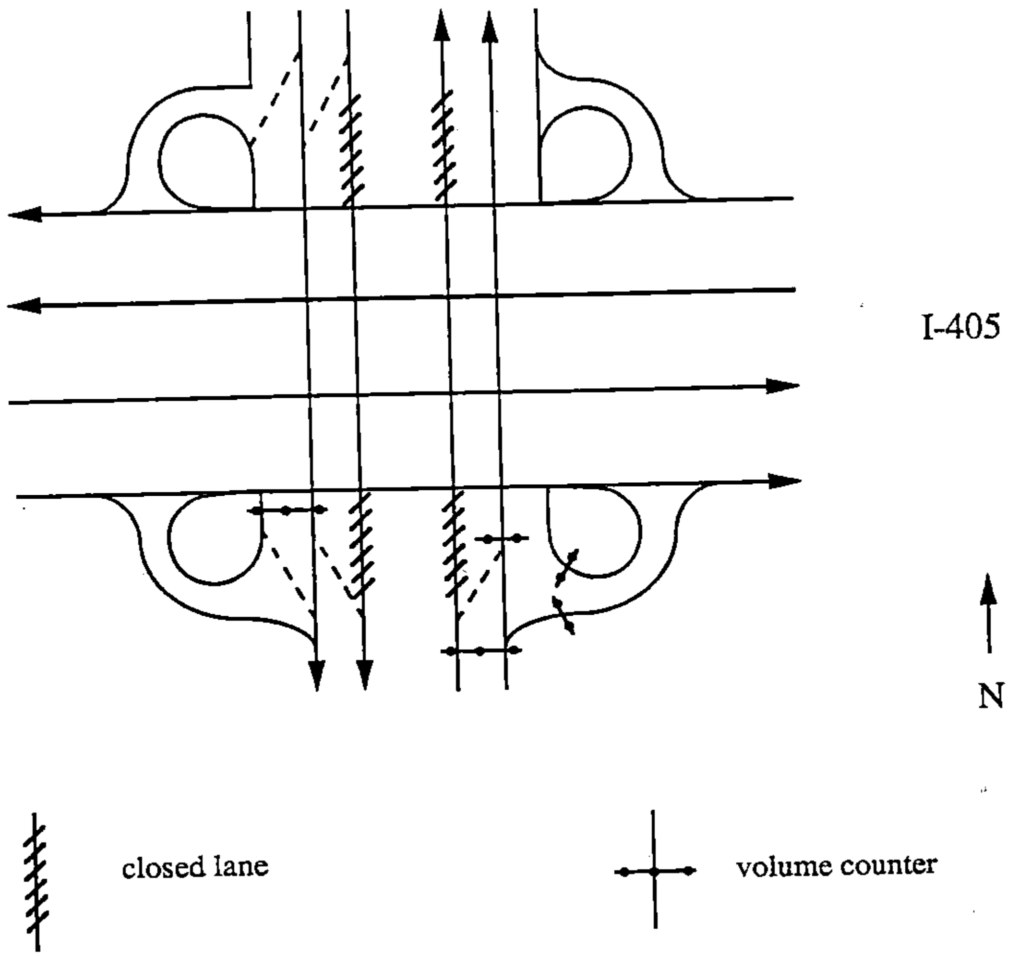
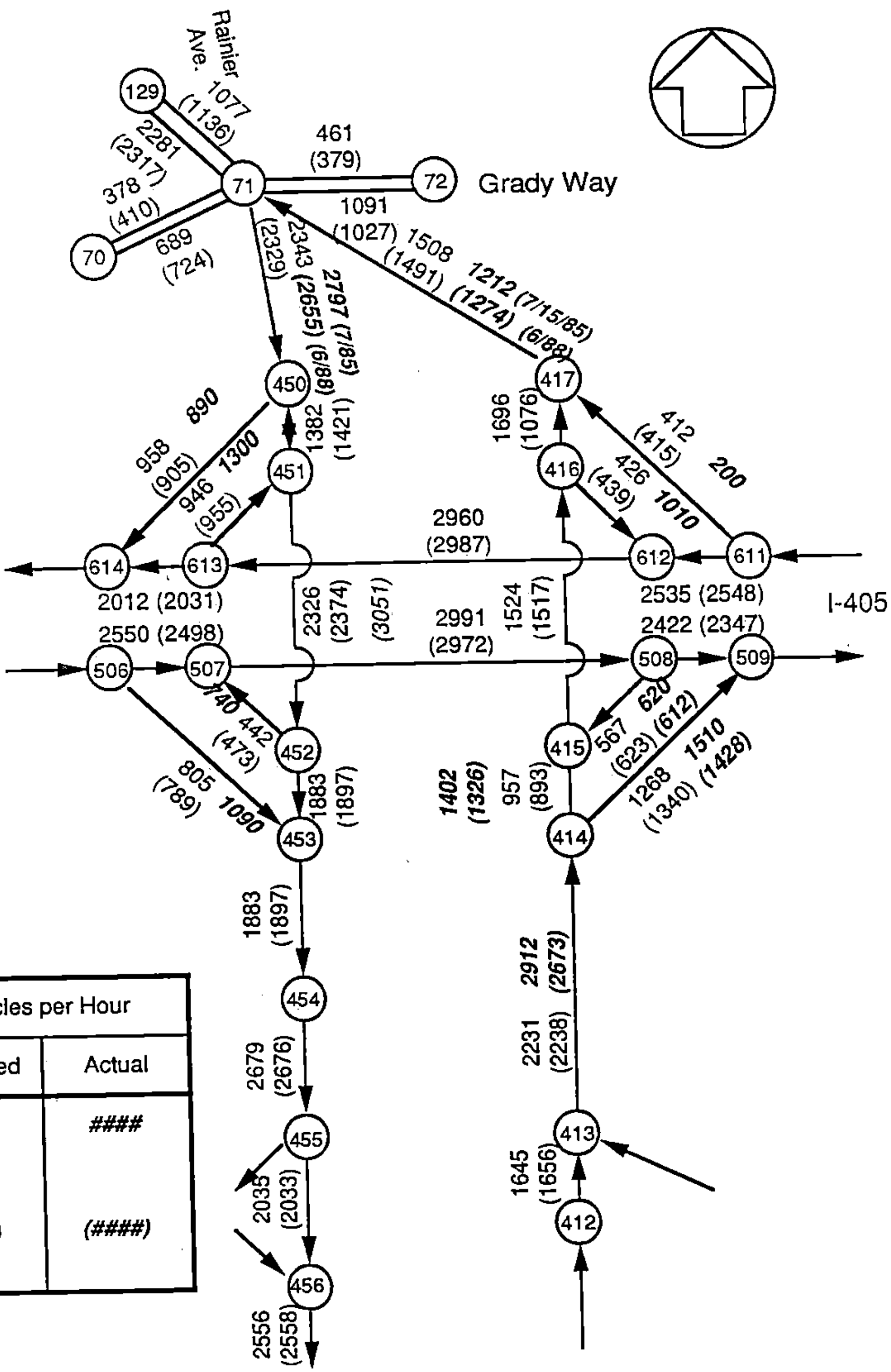


Figure 3.3. SR 167 Lane Closures



	Vehicles per Hour	
	Simulated	Actual
w/out lane closures	####	*####*
w/ lane closures	(####)	*(####)*

Figure 3.4. SR167 Construction Comparison

northbound I-405. The majority of the vehicles were taking the ramp to northbound I-405; therefore, the congestion was not affected by the lane closure but, rather, by the congestion on I-405.

SUMMARY OF EVALUATION

Attempts to calibrate the model to a reasonable level of confidence were unsuccessful. Although volumes on freeway links near the construction were simulated at reasonable levels, simulated volumes on arterials were often significantly different than the volumes measured in the field. In most cases, the speeds simulated by the model did not match what was measured in the field. Because the measured speed varied from day to day depending on the weather (rain or wind), roadway conditions (dry or wet), and light (sunny or overcast), and because of the limited number of days that the speed was measured in the field, the researchers could not say whether CORFLO had correctly modeled the speeds of vehicles.

The simulation of traffic conditions with the construction activity at SR 167 and I-405 did model what was observed in the field. However, this construction activity did not result in large traffic diversions in the way that closing a lane on I-405 would have; thus road closures that have a larger impact need to be studied to adequately test CORFLO.

CHAPTER 4
APPLICATION AND INTERPRETATION

This chapter discusses the special coding requirements of the network, the difficulties that were encountered while the network was constructed, and how the difficulties were handled. Also discussed are the limitations of the model that were discovered during its use.

CODING REQUIREMENTS AND CONVENTIONS

This section will discuss the special situations and difficulties that were encountered in the coding of the network and the steps that were taken to overcome those problems.

Network Size

A first word of caution to the user of the model is that the size of the version of the model that will be used must be determined. The arrays in the program determine the number of links that the user is allowed in the network. The number of links in a particular subnetwork, such as the FREFLO subnetwork, is a parameter set in the Fortran source code and can be easily modified before the program is compiled. The documentation for the model discusses the size of the link arrays, but this is not always consistent with the version sent to the user and should be checked. The manual lists the data statement that contains the array sizes in the source code. The dummy links for exit links created by the program are included in the number allowed by the size of the array and must be calculated into the number of links needed for the network to be modeled.

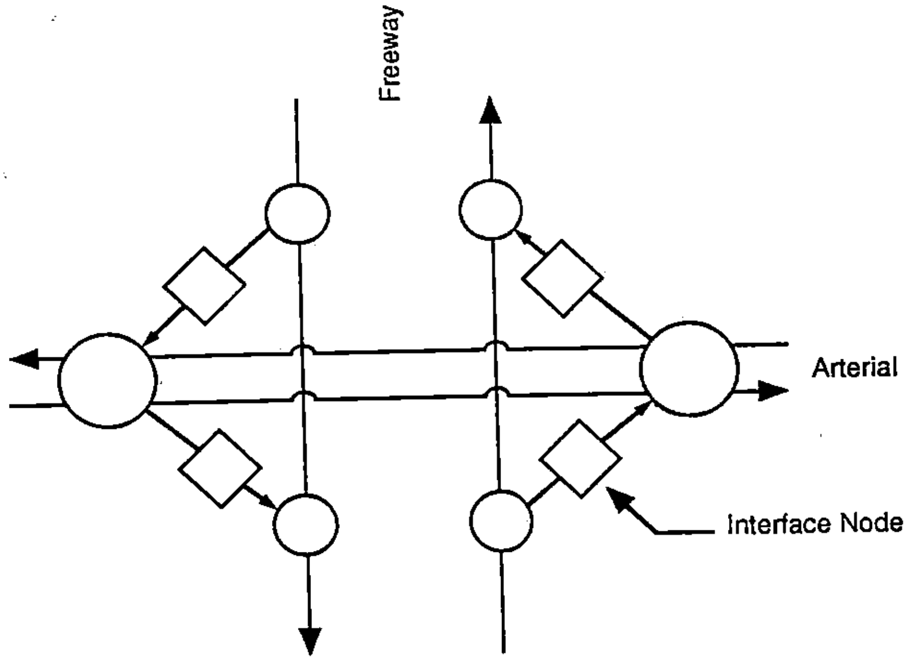
The number of nodes allowed in a particular version is fixed for the version of the model and can not be adjusted by the user. In the version used for this project the number of nodes was fixed at 750. This means that the highest number for a network node is 750. These 750 nodes are for freeways and arterials. This number does not include interface nodes numbered 7000 to 7999, source-link nodes numbered 2000 to 2999, or entry-exit nodes numbered 8000 to 8999.

Freeway Links

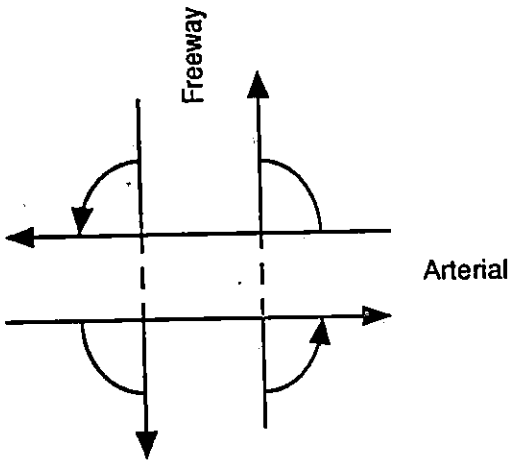
The most difficult coding problem for the freeway network was coding the ramps. At different points along their length, ramps function both as freeway links and as arterials. For coding purposes, the question is at which point does the ramp change from a freeway to an arterial link in cases such as at the diamond interchange shown in Figure 4.1? The method used for this project was to model the first 200 feet of an off-ramp from a freeway to an arterial as a freeway link and the rest as an arterial link. The method was used because the point at which the flow is constricted on the ramp is the intersection where the ramp meets the arterial. Thus it makes sense to model the majority of that ramp distance as traffic traveling on an arterial, impeded by the traffic signal or stop sign at the end of the ramp. A minimum of 200 feet for the freeway link was used because, as discussed in Chapter 3, the freeway links of 100 feet did not appear to be simulated correctly. This finding indicates that the User's Manual should be modified to indicate that a minimum freeway link length of 200 feet is necessary.

The first 50 feet of an on-ramp from an arterial to a freeway were modeled as an arterial link and the rest as a freeway link. The traffic traveling on an on-ramp is only impeded by the flow of the freeway in the downstream section; therefore, the majority of the ramp was modeled as a freeway link.

The collector-distributor lanes were modeled as separate roadways in the network. Collector-distributor lanes can be modeled as either separate roadways that leave the mainline for the distance of the lanes or as additional lanes in the section of roadway involved. Since FREFLO does not model merging actions and does not model the flow in a specific lane but rather distributes it over all of the lanes, there is no significant difference between the methods. The exception to this logic might be when the collector-distributor lanes are congested because of traffic leaving or entering the freeway via the lanes or when collector-distributor lanes are not congested but mainline lanes are. Congestion on the collector may not truly affect the general lanes of the freeway, but modeling the collector-



Link/Node Representation



Actual Configuration

Figure 4.1. Diamond Interchange

distributor lanes as additional lanes will simply distribute the load of traffic to all lanes in the section of freeway.

Another consideration in modeling collector-distributor lanes and freeway interchanges is that a freeway link can only be defined to have two links feeding it and two links exiting it, as shown in Figure 4.2. This requires that all movements at interchanges be specifically coded so that all movements can be independently defined. Figures 4.3 and 4.4 show the link-node representation used for a standard cloverleaf and a full directional interchange for a freeway system.

As with the arterial links, multiple freeway links can not specify the same destination node. Therefore, a dummy link must be created so that all trips leaving the freeway to a destination pass through the same link.

__Arterial Entry Links__

Most trips loaded onto the network entered through connectors to the arterial network. Because an entry link in NETFLO Levels I and II does not have any distance, an extra "dummy" link is required as an entry link if the user desires to realistically represent the turning pockets at the intersection where the traffic enters the network. A second limitation to the CORFLO model is that only one link can connect to each zone from the model network. In order to load the highway network at more than one location for each zone, a series of dummy links are required. A dummy link was used to connect two NETFLO links at a dummy node, and then another dummy link was used to connect this dummy node to the origin node (zone). This same process was used to allow multiple exit points from the network into destination nodes, since no two NETFLO links can specify the same destination node.

__Traffic Signals__

Although the preprocessor of the model does not check the logic of the signal indication (as discussed in Chapter 2), it will not accept an all red phase longer than 15 seconds as the first interval. Sometimes all red periods are needed to model the delay a

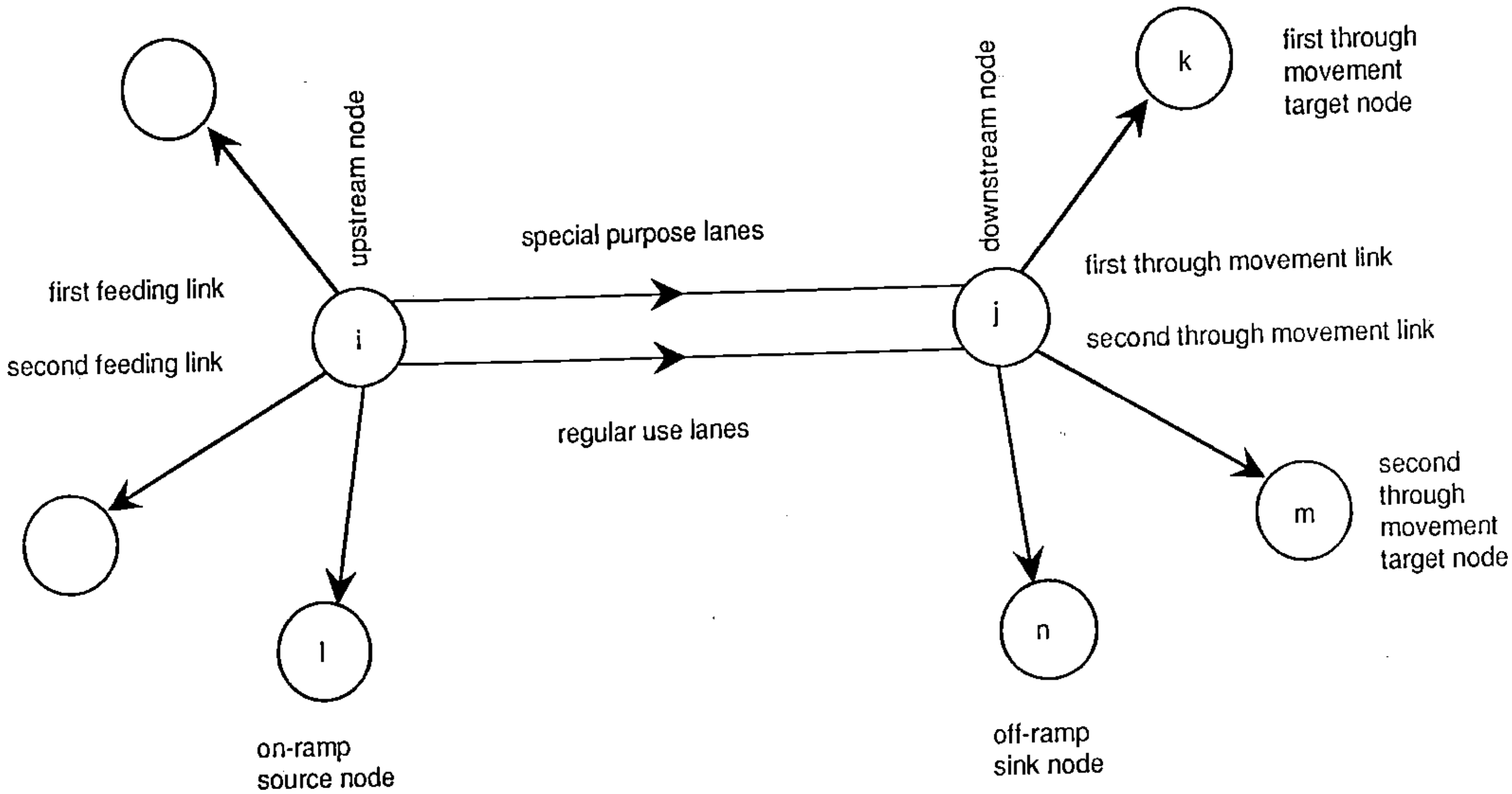
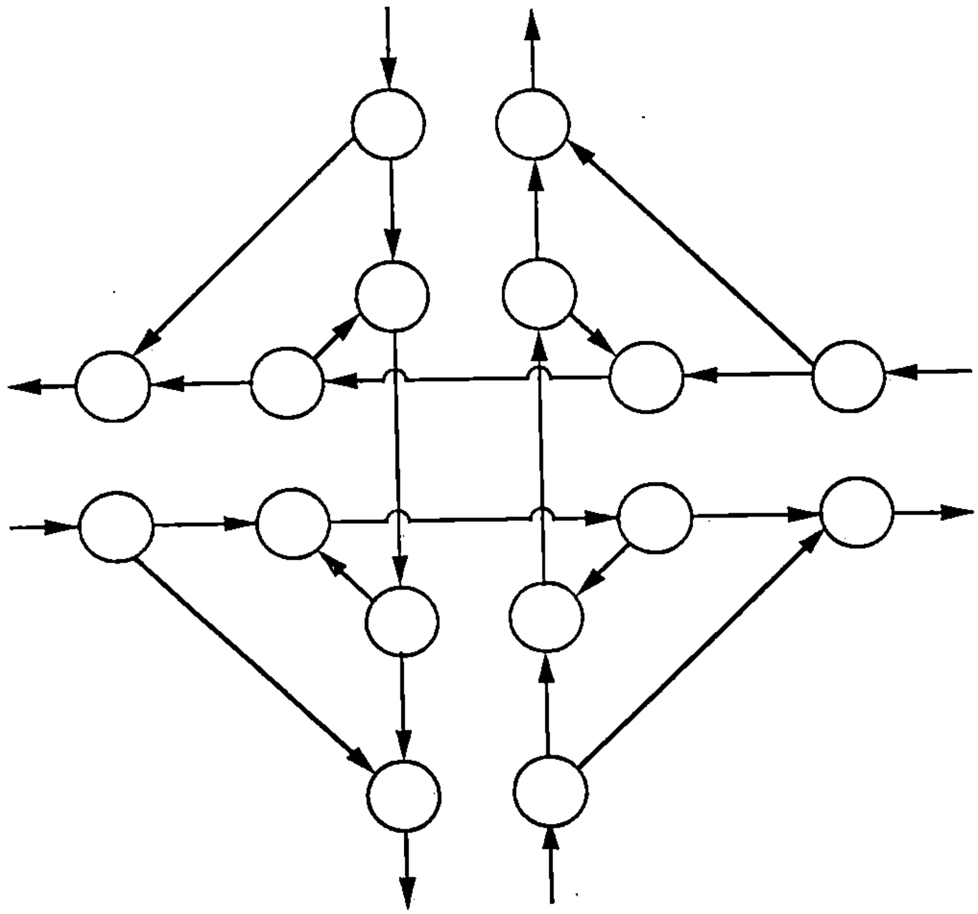
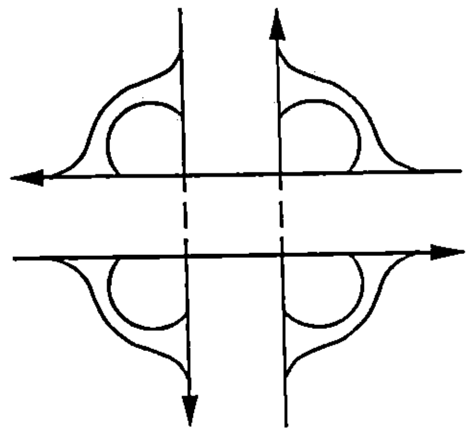


Figure 4.2. General Freeway Subnetwork Link

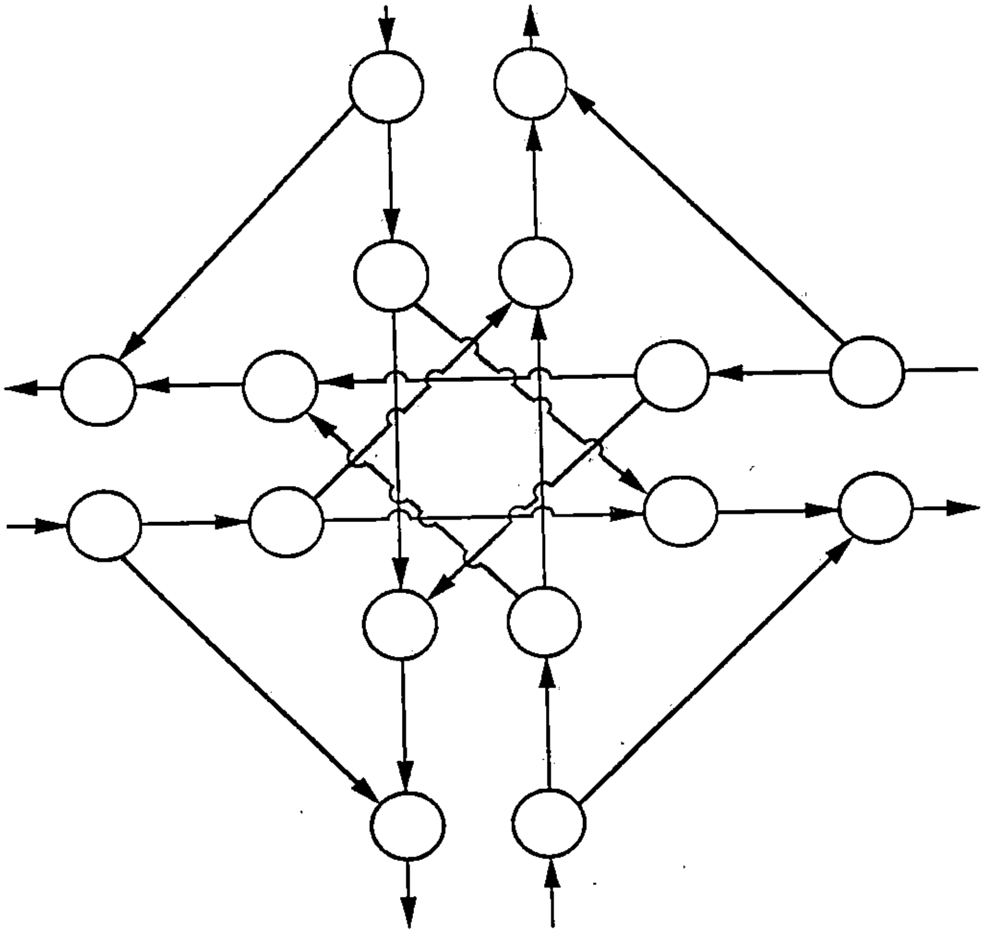


Link/Node Representation

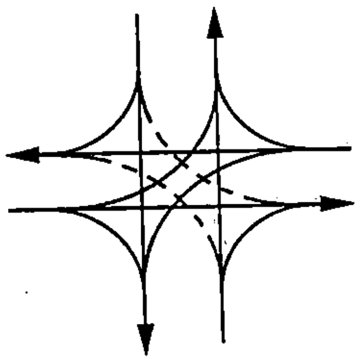


Actual Configuration

Figure 4.3. Clover Leaf Interchange



Link/Node Representation



Actual Configuration

Figure 4.4. Full Directional Interchange

vehicle would experience if it traveled on an arterial when the side street was not being modeled. The all red period would indicate the time the side street would have as green time if it were included in the network. A solution that worked for this problem was to split the all red phase into more than one interval. A signal indication with a right turn only (even though there was nowhere to turn to) also got the preprocessor past this hurdle.

LIMITATIONS OF THE CODING

Arterial Intersections

A problem was encountered in modeling intersections at diamond interchanges. In the Seattle area, off-ramps typically have a traffic signal at the intersection of the ramp with the arterial. A problem was encountered in specifying that the middle lane could turn left or go straight, as shown in Figure 4.5. There are no lane channelization codes that allow a through- and left-turn movement from the same lane without the lane being coded as unrestricted. If the middle lane is unrestricted it will not be used as a left-turn lane, since the logic of the model requires that left turning vehicles turn from the left-turn pocket, if one is provided, or from the left-most unrestricted lane if there is no left-turn pocket. In most of the cases this problem was handled by eliminating the through movement, since vehicle counts indicate that this movement is rarely used at these locations. The middle lane is then coded as a left-turn only lane, as is shown. This method of eliminating through movements will not work at the intersections of arterials that have option lanes.

A limitation was found in the lane channelization coding. If a "T" intersection has only one full left-turn lane and a right-turn pocket, the full lane must be channelized as an unrestricted lane. Similarly, if two full lanes turn right and a third is a left-turn pocket, the model will not allow both full lanes to be channelized as right turn only lanes. This problem was overcome by specifying the full lanes as unrestricted lanes and specifying the through node as the node to which the vehicles would really be turning left or right.

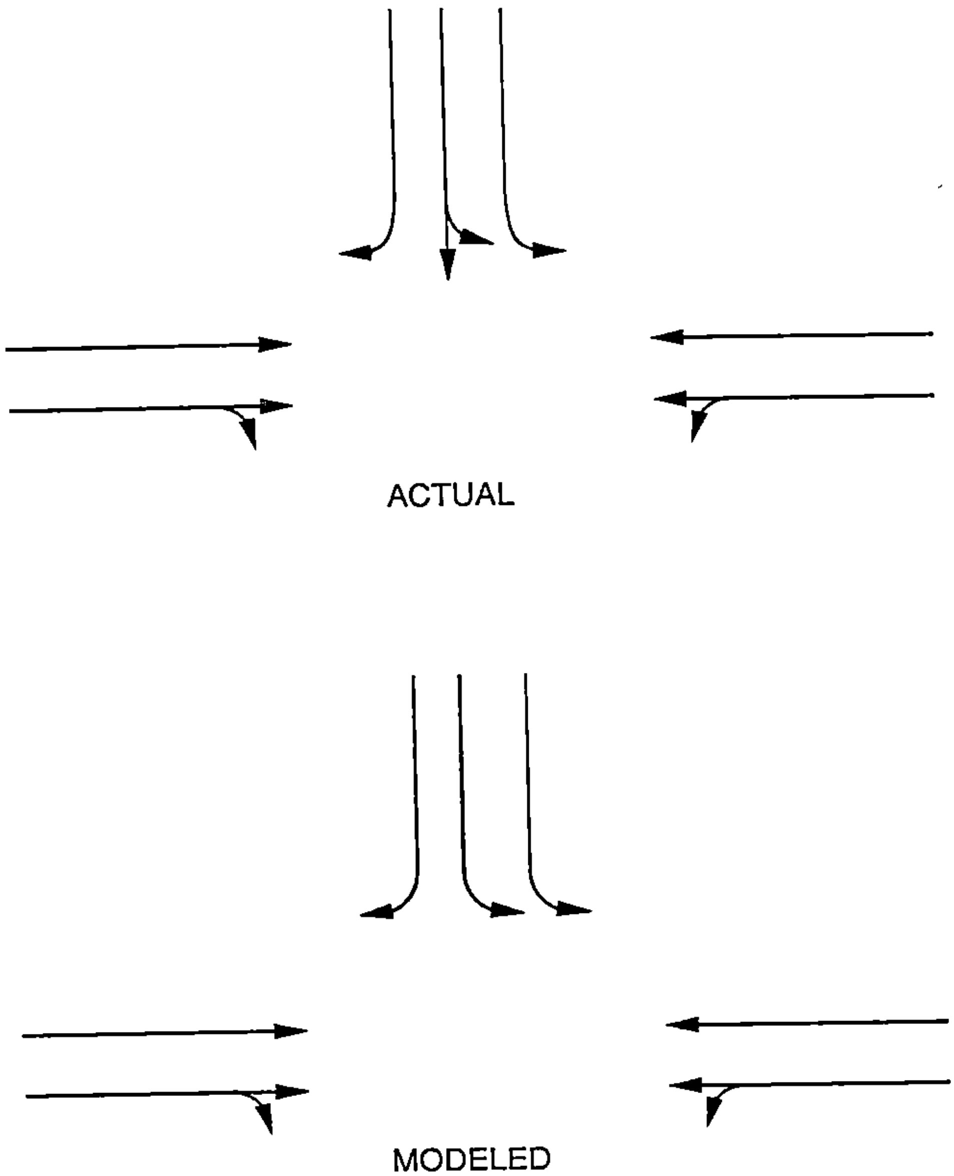


Figure 4.5. Line Diagram of Off-ramp Intersection

However, this procedure did raise some concern, since the capacity of right-turn and through vehicle lanes is not the same in most flow models as that of left-turn lanes.

Fixed-Time Signals

The fixed-time signal card types 35 and 36 are used to specify duration and movements during each phase of the cycle. The input for these cards limits the number of intervals for a signal to nine, which may not be enough to adequately describe the operation of the signal for a standard, dual ring controller acting as a fixed-time controller. A fully actuated traffic signal can have up to 12 intervals if each approach has protected left turns. This is shown in Figure 4.6. Since only nine intervals are allowed, the intervals with the opposing left with a yellow signal (intervals 2,4, 8, and 10) were combined with the opposing left turn's green phase just before the eliminated interval. This created artificially long green indications. These green times may have lead to unrealistic capacities at an intersection if the model simulated vehicles differently during a green light and a yellow light.

Another limitation of the NETFLO Level II model is that the signal timing can only be input for the first time period. An actuated controller reacts to the traffic conditions at the approaches to the intersection. If the traffic conditions change because of the diversion of traffic, the signal timing changes. Since the signal timing is only input for the first time period, the changes in the signal timing resulting from diversion in a following time period are not simulated.

Origin/Destination Information

Another limitation discovered in the coding is that the percentage of carpools and trucks that leave a particular origin are not allowed to vary depending on the destination. For example, the model requires the same percentage of trucks to be assigned from a commercial zone to a residential zone as from the commercial zone to another commercial zone. This could represent a problem in the type of traffic being modeled on routes in the study area. Since some areas in a network may have high concentrations of commercial activity, especially during off peak hours, the percentage of trucks can be significant. A similar argument can be applied to carpools, which vary from the same origin to different destinations.

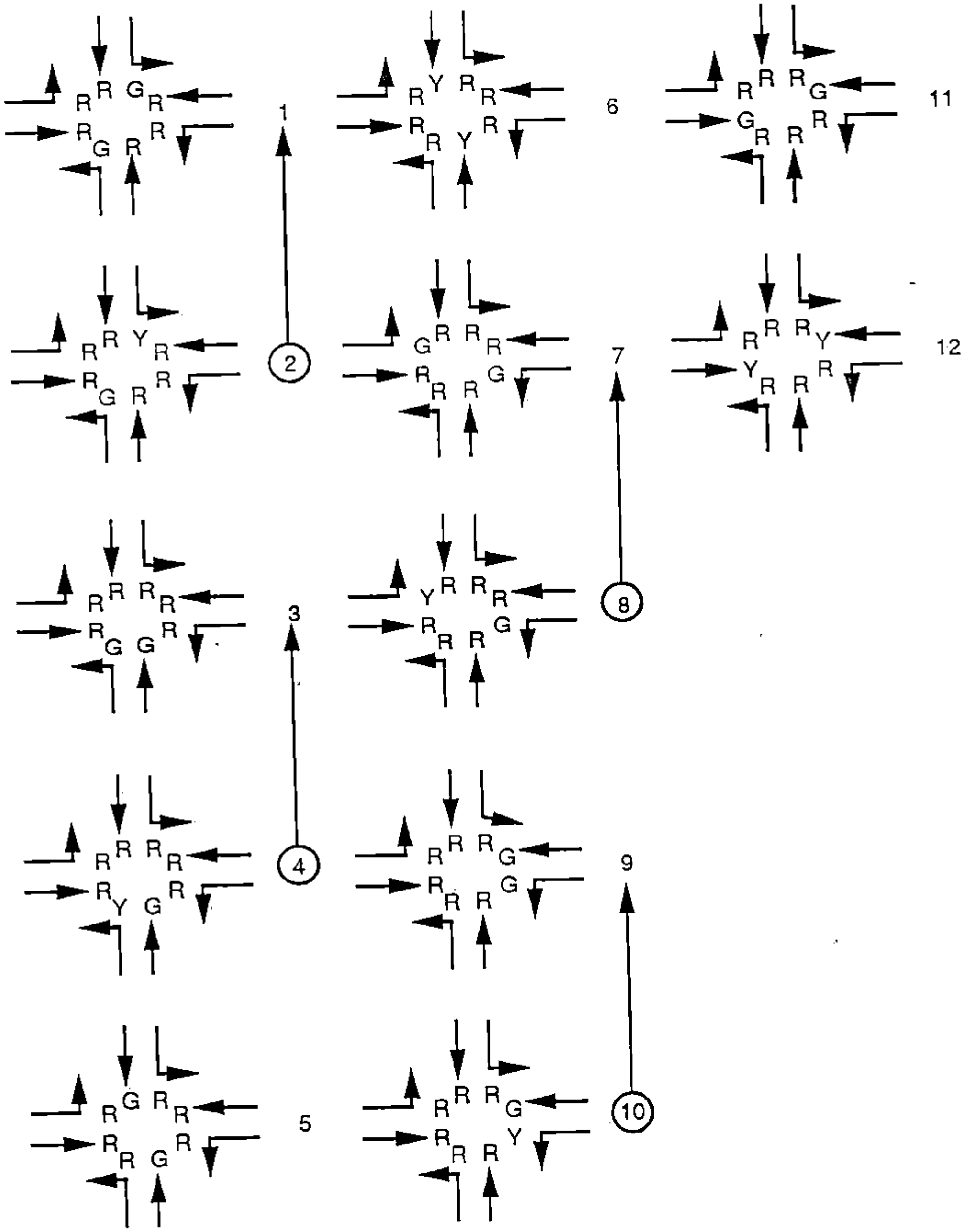


Figure 4.6. Actuated Traffic Signal Phases

CHAPTER 5
RECOMMENDATIONS AND CONCLUSIONS

RECOMMENDATIONS

This chapter presents the conclusions drawn by the project team as a result of its preliminary analysis. Where appropriate, recommendations for improving the capabilities of the model are presented, and recommendations for further work under this contract are made.

Research of the Traffic Assignment Model

More research is needed on the traffic assignment model to determine why trips were assigned off of the freeway and through a signalized intersection, then back onto the freeway. Even though this does happen when the freeway is congested and the ramp is not, the model was assigning a large number of trips with average speeds as low as 0.1 mile per hour onto the ramp. Since the freeway was still at 38 mph, the vehicles could not have saved time by traveling off the freeway and then back on. This assignment problem only existed if the freeway was congested and operating at speeds less than 40 mph.

Improve NETFLO Level I Signal Modeling

Many traffic signals that are not part of a downtown grid network of streets are operated by actuated or semiactuated controllers. To adequately model the diversion that occurs because of construction activities, the NETFLO Level I model should be expanded so that dual ring controllers can be modeled. The signal time is calculated into the traffic assignment portion of the model, and yet with an actuated signal the timing changes with the change in demand. The user is thus required to manually change the model's fixed time signal settings if the effects of diversion are to be modeled correctly.

Improve Coding Ability

The lane channelization codes that specify the lane movements as unrestricted, right only, left only, closed, or special use by HOVs should be expanded with an exclusive turn lane and an option through or turn lane can be explicitly modeled. This may require a change in the logic of the flow model, but this condition exists and should be realistically modeled.

Possible Enhancements

Future enhancements that might make the model easier to use are a data input manager and graphical display of the output data. An input manager could aid the user by assuring that the data were input into the correct format and by checking the reasonableness and completeness of the data. Computer graphics could enhance the ability of the user to analyze the results of the simulation. It is difficult and time consuming to follow the flow of vehicles in the network by looking at output that lists statistics by link.

CONCLUSIONS

The CORFLO model is an integrated model that can simulate traffic on a network with both arterials and freeways. The models that are included in CORFLO have enjoyed successful use in their independent versions of TRANSYT, MACK, and the traffic assignment model. However, CORFLO does not appear to be an appropriate model for the reconstruction application attempted in this project for several reasons. First, the origin/destination information that was readily available for this area was not at the same level of detail required by the model. The model is designed so the approach to each external intersection is both an origin and a destination, and the model assigns turning percentages appropriately. The use of the regional traffic analysis zones for origins and destinations made it difficult to load the traffic onto the network through real intersections with real signal timings. The traffic realistically enters the network at many points throughout the network within the zones. This means that the zones are too large for the level of detail provided by the model. Since the model only allows one link to attach the network to an origin/destination node, a maze of dummy links is required to distribute the trips throughout the zones.

A solution to this problem is to obtain a more detailed origin/destination table through methods such as origin/destination surveys. These surveys are costly and well beyond the scope of this project. Perhaps a more detailed origin/destination table could be gathered for the small portion of the network that was of most interest. The problem with this idea is that the diversion that occurs on routes not in the network would not be modeled. Another option would be to use existing planning models to disaggregate the traffic assignment zones and develop a corresponding origin/destination table outside of the CORFLO model's environment (e.g., we use the UTPS package to focus on the study area). The synthesized origin/destination table and/or back volumes could then be used as input to CORFLO. However, for the model to be most helpful, it should be designed to use as many existing data sources as possible. The model would be applicable to the widest range of reconstruction projects if users could utilize existing planning zones and existing trip tables as O/D input.

Turning movements could have been used at each intersection to replicate the existing traffic conditions, and the researchers were confident that this would have resulted in a closer calibration of the model. The problem with this approach would have been that diversion could not have been modeled using the traffic assignment model, since origin/destination information would not have been used. The effects of construction activities on the network would only have been measured in terms of the measures of effectiveness produced by the model, such as delay, speeds, and travel time, and not in terms of the expected diversion.

A major objective of including the traffic assignment model in CORFLO is to make CORFLO useable for planners as well as engineers. This study demonstrated that the level of detail required by the simulation models surpasses what is normally available for most regional planning studies.

FUTURE DIRECTION

As a result of the research thus far, two areas of emphasis are appropriate for concentration during the remainder of the project.

Simulation Using Turning Movements

More investigation of the simulation components of the CORFLO model is warranted. Because of the questions surrounding the traffic assignment model and the zone structure selected for the project, no conclusive results have been found regarding the simulation model itself. The strength of the CORFLO model lies in its ability to simulate arterial and freeway subnetworks through the interface nodes. Yet it is unclear whether the calibration difficulties the project team has experienced so far are related to the simulation portion of CORFLO, the Origin/Destination data, the traffic assignment model, or the interaction of the traffic assignment model and the simulation model.

In order to examine and test the simulation model without being subject to the possible limitations of the assignment model and the zone structure, the next effort in this project will focus on simulation only. Turning movements will be coded for the network and the model will be calibrated for existing conditions. The model will then be used to simulate lane closures caused by the construction projects in the area. The model will be evaluated on the basis of how well the simulated conditions reflect the actual conditions.

Investigation of the FRESIM Model

One of the elements of the TRAF family of models that has not been extensively tested is the FRESIM model. FRESIM is a microscopic freeway simulation model based on the INTRAS model. After the simulation portion of the CORFLO model has been examined, FRESIM will be tested, as allowed by remaining project resources. This testing of FRESIM is within the intentions of the project, in that FRESIM was originally part of the TRAF modeling package.

While the FRESIM model is not relevant to the modeling of diversion and traffic performance through the I-405 study area, the model can be used to examine other important facets of the I-405 HOV lane construction effort. The project team recommends that FRESIM be used to examine the cross-over movement required of HOV vehicles using the new HOV facilities. This movement is necessitated by the placement of the HOV lanes on the left side of the roadway south of Park Drive and their placement on the right side of the roadway north of State Route 169 (see Figure 5.1).

Specifically, the FRESIM model will be used to examine the following:

- whether the required vehicle movements create a safety hazard,
- whether the vehicle movements significantly reduce freeway capacity (or at what level of HOV lane usage is capacity significantly reduced), and
- whether the distance provided between the end of the left-hand HOV lane and the beginning of the right-hand HOV lane sufficient for the vehicles to make the transition between HOV facilities.

Results of the analysis, along with comments on the capabilities and weaknesses of the FRESIM model, will be produced at the end of the project.

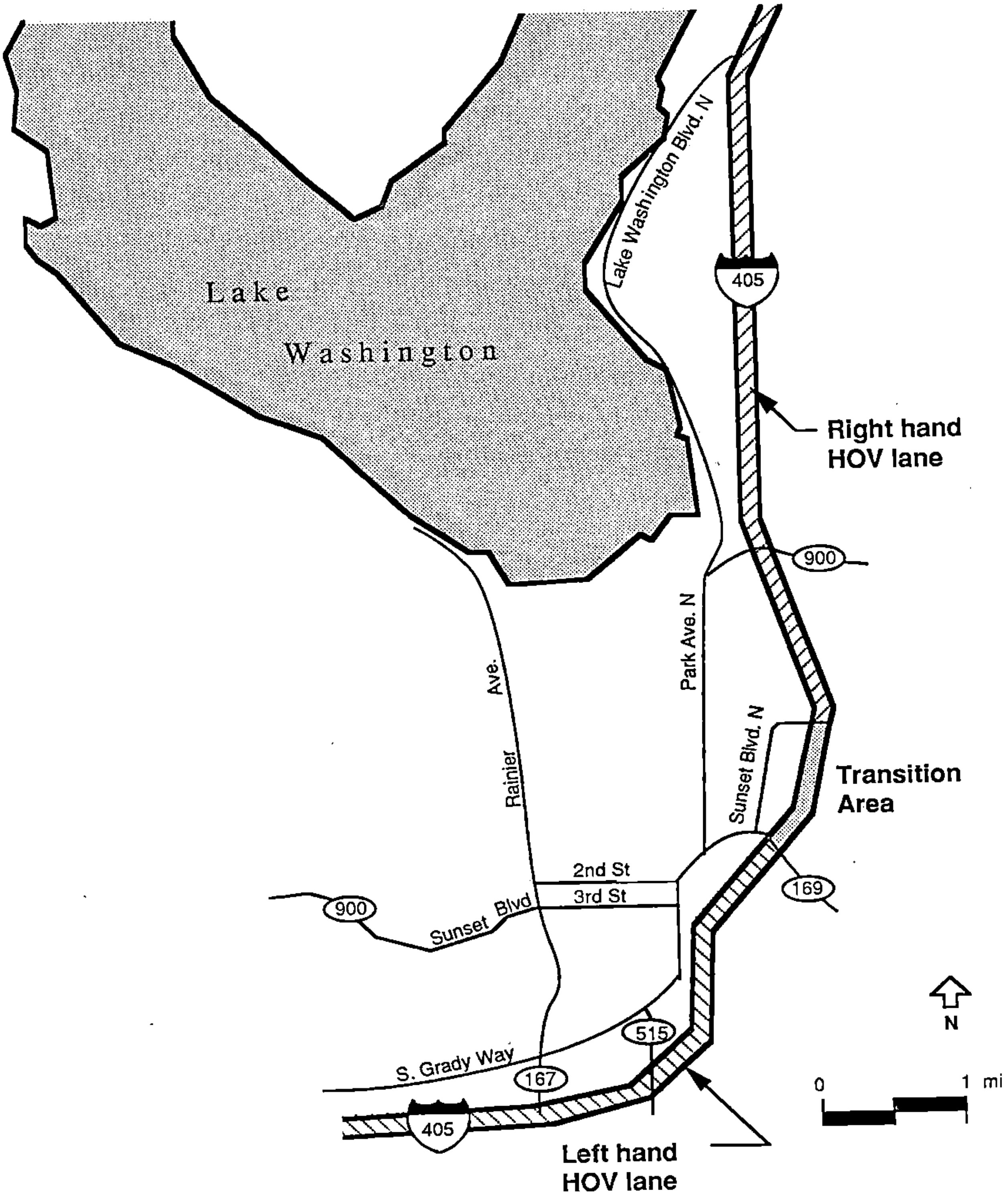


Figure 5.1. HOV Lanes on I-405

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2. Highway Capacity Manual, Special Report 209, Transportation Research Board, 1985

3. TRANSYT-7F User's Manual, Federal Highway Administration, Revised June 1984

4. UTPS Reference Manual, Urban Mass Transportation Administration, December 1984.

5. "Ramp and Roadway Traffic Volumes, Summary Report," Washington State Department of Transportation, Jan/June 1986.

APPENDIX A
CORFLO MODEL DESCRIPTION

This appendix describes the CORFLO model. The method of simulation for each submodel is described, along with the input required for and the output produced by the program.

MODEL DESCRIPTION

The CORFLO program is a set of macroscopic, simulation models for networks containing freeways and arterials. Although the component simulation models in CORFLO are based on deterministic models, a stochastic feature has been added in the form of a random seed number to provide some variability to the model. The model uses a time scan technique to simulate the flow of vehicles on the network. The model can be used in two ways. For traditional simulation, the operating parameters and volumes are put into the model, and the program calculates the delay, miles traveled, speeds, and other measures of effectiveness. The traffic assignment model can also be used in the simulation so that the model loads the network based on origin/destination data. The program thus calculates not only the measures of effectiveness but also the volumes assigned to each link in the network on the basis of the minimum travel time.

The program can also be used to model traffic flow over changing conditions in time. The program accomplishes this by dividing the simulation into time periods specified by the user. The time periods, which can be of different durations, are used to modify certain time dependent inputs during the course of the simulation. These inputs represent changes in volumes, turning movement percentages, lane channelization, or signal timing. The time periods are further broken down into uniform "time intervals," which the model uses to determine the length of time each submodel should be brought into memory. During the time the submodel is in memory, the traffic in the subnetwork is simulated and the results accumulated before the next submodel is brought in. The simulation statistics are available to the user on a time interval basis, as specified by the user. A graphic depiction of the relationship between time periods and time intervals is shown in Figure A.1. In general, the time interval duration approximates the average signal cycle length, and the time period must be specified as a multiple of time intervals.

The CORFLO Model is a part of the larger family of models termed TRAF. The models are being developed for the Federal Highway Administration. The TRAF family consists of the following components:

- TRAF Input Processor
- Component Model (Subnetwork) Integration Processing
- Microscopic Rural Road Simulation Model (ROADSIM)
- Microscopic Arterial Simulation Model (NETSIM)
- Macroscopic Arterial Simulation Model (NETFLO Level I)
- Macroscopic Arterial Simulation Model (NETFLO Level II)
- Macroscopic Arterial Simulation Model (NETFLO Level III)
- Microscopic Freeway Simulation Model (FRESIM)
- Macroscopic Freeway Simulation Model (FREFLO)
- Equilibrium Traffic Assignment Model.

The CORFLO model, which was used for the initial effort in this project, is a portion of the macroscopic models from the TRAF family of models. The model was developed as a separate unit of models to be adapted into the future ITDS system being developed for the FHWA. The model consists of the Macroscopic Arterial Simulation Models (NETFLO Levels I and II), the Macroscopic Freeway Simulation Model (FREFLO), and the Equilibrium Traffic Assignment Model. The necessary input processor and model integration programs are also included in the stand alone CORFLO model.

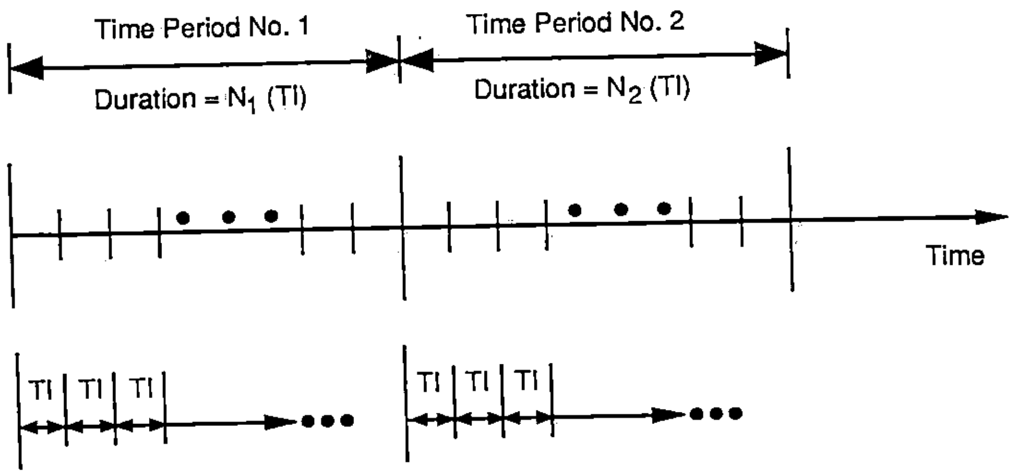

Figure A.1. Relationship between Time Interval and Time Period Durations

INPUT PROCESSOR

The TRAF family software package uses traffic simulation models by integrating the different models as subnetworks in the overall network. This means that a portion of the arterials may be modeled with different levels of detail, as may portions of the freeway. An arterial may be modeled by a macroscopic simulation model on the external portion of the network where detail is not as important and by the microscopic simulation model, NETSIM, in the area where the most detail is desired.

The complexity of integrating these models requires an input processing program that runs a series of diagnostic tests on the input data. The input data are arranged in a series of input "cards," which are lines of input data. The input processor checks for

1. correctness of the input arrangement,
2. the completeness of the input,
3. the reasonableness of the data within the range established in the documentation,
4. the consistency of the data items within the subnetwork being described,
5. the completeness of the data items for the subnetwork being described, and
6. the completeness of the entire network being modeled.

Messages that are produced by the program are documented and consist of either a warning message or a "fatal" error message. The warning messages are used to alert the users to data input that is unreasonable or unusual but that will not cause the simulation to terminate. The "fatal" error messages describe data inputs that are missing or incorrect and cause the program to abort without beginning the simulation. The input processing continues, if possible, through the entire input card deck before simulation begins. If no "fatal" errors are detected and the user has specified that the program should continue following the preprocessing, the simulation is performed.

COMPONENT MODEL INTEGRATION

Since CORFLO consists of several models that simulate the flow of vehicles in different manners and with different amounts of detail, the models must be integrated to allow vehicles to pass from one link in a subnetwork to a link in another subnetwork. The component model integration program represents the traffic stream in a common format so that the flow of vehicles can be modeled over the different type of links in the network. The simulated vehicles exiting a subnetwork enter a "vehicle holding area" called an interface node and are held there as individual vehicles until the program finishes modeling that subnetwork for that time interval. The next subnetwork picks up those vehicles from the interface node and continues the simulation for that subnetwork for the same time interval. This means that a vehicle that travels on the freeway, exits the freeway via an interface node, and then continues on an arterial can be modeled. This ability to interface the different subnetworks is the strength of the CORFLO model.

NETFLO LEVEL I MODEL

The NETFLO Level I model simulates each vehicle in the stream of traffic as a separate entity moving along the roadway during each event. Each vehicle in the traffic stream is identified by

- the type of the vehicle (auto, carpool, truck, or bus),
- the driver's behavioral characteristics (aggressive or passive),
- the status of the vehicle in the traffic stream at the event (queued or in freeflow),
- the location of the vehicle in the network (the location of the vehicle on the arterial and the lane the vehicle is traveling in at the time), and
- the kinematic properties of the vehicle, including the speed of the vehicle and the acceleration characteristic of the vehicle.

These behavioral characteristics are assigned stochastically to the vehicles in an attempt to model the variability of drivers.

This model approaches the definition of a microscopic simulation model but is different in that the model does not move each vehicle based on a car following theory, as does NETSIM. The NETFLO Level I model moves each vehicle during each event modeled. Therefore, it can not describe the trajectory of each vehicle through each second of simulation. Each vehicle is moved as a "jump" occurring during each event simulated.

This model has the capability of modeling the traffic stream through a network with actuated traffic signals, which is the major feature not available in the NETFLO Level II model.

The user can assign turning movements in the NETFLO Level I model in two ways. The user can specify the percentage of turns on each link for each intersection or the probability of a vehicle turning at each intersection, depending upon the upstream movement from which the vehicle came.

NETFLO LEVEL II MODEL

The traffic flow model of TRANSYT was adapted to the CORFLO modeling format in the NETFLO Level II model. The links modeling method in TRANSYT was modified to more closely follow along the method used in NETSIM. In TRANSYT, each movement at an intersection is defined as a separate link in the system, and the user inputs the movements from the upstream intersection that feed the link being described. In CORFLO, an arterial link is defined as the directional link between adjacent nodes. The number of through lanes are coded rather than the capacity, which is used in TRANSYT. Left- and right-turn pockets are defined as a part of the link. The user inputs the length of the pocket and the number of lanes in each pocket. The movement of each lane is defined by a series of lane code inputs that describe each full lane as a right turn only, left turn only, unrestricted lane, closed lane, or bus only lane. Although this reduces the input requirements from the TRANSYT format, it also limits the user in describing unusual lane configurations, as was discussed in Chapter 4.

NETFLO Level II models the traffic as a flow of aggregated vehicles rather than as independent vehicles, as used in NETFLO Level I or NETSIM. A histogram approach models the flow of vehicles as a "platoon" of traffic that is spatially distributed, as displayed in Figure A.2. The histogram approach to modeling the traffic flow attempts to

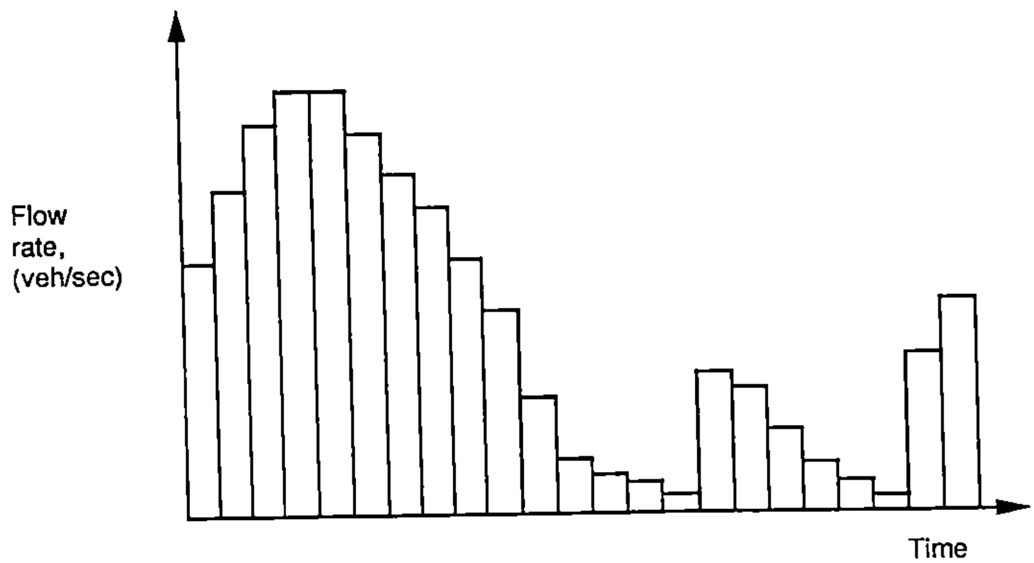

Figure A.2. Typical Statistical Flow Histogram Employed by Level II Model describe the dispersion that occurs as vehicles travel along a roadway. The departure from a traffic signal and the arrival at a signal are modeled as a histogram of dispersed vehicles, and flow rates are calculated at the point in time of interest.

Buses can be modeled as individual units. The measures of effectiveness for buses is calculated with kinemetric relations, including the dwell times for the buses. The effects of traffic congestion and spillback are modeled and captured in the calculations for travel time and speed. The NETFLO Level II logic does not model carpools and differs from TRANSYT in that fixed-time signal cycles with different cycle lengths can be modeled.

FREFLO MODEL

FREFLO is the macroscopic freeway simulation model in the CORFLO program. The model is an adaptation and refinement of the MACK model. The main refinements of the earlier MACK models include the following:

- different vehicle types can be modeled separately and distinguished as either autos and trucks, carpools, or buses, and
- freeway segments can be modeled as a disjointed system with on- and off-ramps to other freeways and collector-distributor lanes. Previously, MACK models could only deal with single linear freeway segments.

The normal capability of a freeway model involves the use of a particle conservation equation and a speed-density relationship. FREFLO and MACK use a refined equilibrium speed-density relationship, which is incorporated into a dynamic speed equation. [A1] The flow of vehicles on a FREFLO link is modeled as an aggregated flow and represented by the number of vehicles entering and leaving the link, the density of the vehicles on the link, and the space-mean speed on the link.

FREFLO is able to model the vehicles entering the freeway through either the upstream freeway segment or through on-ramps. A freeway link may be used to model the vehicles on the ramp or the user can code the ramp so that vehicles are input at the ramp gore and merge immediately. This procedure is the same for off-ramps. Ramps between freeways are modeled as freeway links, as are collector-distributor lanes.

The user can define two types of lanes on a freeway link in the FREFLO model, general purpose lanes or lanes restricted for buses and/or carpools. The model does not know which physical lane is the restricted lane but, rather, asks for the number of restricted lanes and the number of general purpose lanes. The flow of vehicles is uniformly distributed over the number of lanes associated with the type of lane.

Buses are modeled as separate vehicles in the FREFLO model so that bus travel times can be tracked, but the buses are accounted for in the overall traffic stream so that the impact of the vehicles can be measured in terms of the freeway segment.

As with the arterial network modeled in NETFLO Level I and NETFLO Level II, the turning percentages can be assigned at freeway links.

TRAFFIC ASSIGNMENT MODEL

The latest traffic assignment model adapted for CORFLO contains the option for system optimal or user equilibrium traffic assignment. This project used the user equilibrium option. A user equilibrium traffic assignment model assigns the trip to a route so that all vehicles experience the same travel time on all of the used routes. By this method, a vehicle can not improve its travel time by unilaterally changing routes.

The traffic assignment was improved from TRAF's earlier model, which was evaluated by Labrum of the Utah Department of Transportation and by the Institute of Transportation Studies at the University of California, Irvine. [A2, A3] Left- turn penalties have been incorporated into the assignment. The algorithm used in the assignment model is a variation of the Frank & Wolfe decomposition iterative technique. [A1] During each time interval, the traffic assignment model computes the shortest path that each vehicle selects to reach its destination. This path time is interpreted by the model as the impedance experienced by the vehicles in the traffic stream and the delay the vehicles experience at the signals. The delay at signals is calculated by the ratio of green time to the cycle length. The travel time on each route is then recalculated based on this loading, and the shortest path is recalculated for the next time interval. This process is continued until the content of vehicles on a subnetwork changes by less than a specified percentage. This state is then called "equilibrium" for that subnetwork, and the process continues until equilibrium is reached on each subnetwork. Once equilibrium is reached, the simulation begins and simulation statistics are accumulated.

The assignment model can be used for user equilibrium assignment, as described above, or it can make the vehicles select the paths that would minimize the total travel time of vehicles in the system. This creates a situation known as "system optimal" assignment. The user has the option of inputting the parameters used in the formulae for the assignment calculations, or the default values may be used.

The impedance, which is calculated for each link, can be calculated by either the FHWA Formula, which is a version of the standard BPR Formulae, or may be calculated by the Modified Davidson Formula. [A1]

A new "Shortest Path Algorithm" was also included in the version of the traffic assignment model used for this project. This algorithm reduces the computer time necessary to calculate the paths.

No documentation is available for the traffic assignment model incorporated into the CORFLO model.

INPUT/OUTPUT

Input

The input to CORFLO consists of three basic sets of input cards (card images), as follows:

- run-specific cards, which range from 00 to 09 and are arranged at the beginning of the data;

- subnetwork-specific cards ranging from 10 to 170 that specify the attributes of the network; and
- global-specific cards ranging from 175 to 210 that specify attributes that are common to all subnetworks.

The data cards can be further grouped into control cards, link characteristic cards, flow characteristic cards, signal characteristic cards, volume cards, traffic assignment cards, bus cards, and delineation cards. Table A.1 contains a summary of the data cards available in the CORFLO program.

The control cards required for operation of the program are as follows:

1. Card type 00 — title card with identifying information,
2. Card type 01 — identification card with the user's name, date, agency, and run identification data,
3. Card type 02 — run control card that identifies the models to be used in the run, the estimate of the initialization time to fill the network, and other information about fuel consumption options, clock time, random seed number, and English or metric unit codes,
4. Card type 03 — time period specification card detailing the duration of each time period in the simulation,
5. Card type 04 — time-step control card with the length of the time interval to be used during the simulation and the number of time slices per time interval for the NETFLO Level II model, and
6. Card type 05 — output options card.

The link characteristic cards are Card type 11 for the arterial NETFLO links and Card type 15 for the freeway FREFLO links. The link information consists of the upstream and downstream nodes, the length of the link, number of lanes, turn pockets for arterial links, channelization codes for arterial links, downstream nodes, which receive the

Table A.1. CORFLO Input Card Types, by Model

	Card Type	Description	Level I	Level II	Freflo	Traffic
Control	00	Title	R	R	R	R
	01	Identification	R	R	R	R
	02	Run Control	R	R	R	R
	03	Time Period Classification	R	R	R	R
	04	Time-step Control	R	R	R	R
	05	Output Options	R	R	R	R
Link Characteristics	11	Urban Link Characteristics	R,O	R,O		R
	15	Freeway (Freflo) Link Characteristics			R,O	R
Flow Characteristics	21	Urban Street Turning Movements	R,O	R,O		O
	26	Freeway (Freflo) Turning Movements			O,O	
	27	Freeway (Freflo) Incident Specifications			O,O	
	34	Freeway (Freflo) Parameters			O	
Signal Characteristics	35	Sign or Pre-timed Signal Control Timing	O	R		R
	36	Sign or Pre-timed Signal Control Codes	O	R		R
	39	Actuated Controller Specifications	O			O
	40	Phases for Actuated Controller	O			O
	41	Phase Operations for Actuated Controller	O			O

Legend: R - Required; O - Optional; Blank - Not applicable (omit card type)
Entries are of the form R; O; R,O; O,O; R,R
If of the form R or O, the card type can be input for the first Time Period, only
If of the form R,O; O,O; or R,R, the card type can be input for the first Time Period (TP) as specified by the first code and for subsequent Time Periods (if any), according to the second code.

Table A.1. (continued)

Volumes	50	Entry Link Volumes	O,O	O,O	O;O	
	51	Source/Sink Volumes	O,O	O,O		
	52	Load Factors	O,O	O,O	O,O	
	170	Subnetwork Delimiter	R,R,	R,R	R,R	R
Traffic Assign-ment	175	Traffic Assignment Parameters				O
	176	Origin-Destination Trip Table				R
	177	Internal Centroids				O
Bus Cards	185	Bus Station Para-meters	O	O		
	186	Dwell Times	O,O	O,O		
	187	Bus Paths	O	O	O	
	188	Bus Routes	O	O		
	189	Bus Flow	O,O	O,O	O,O	
	210	Time Period Delimiter	R,R,	R,R	R,R	R

Legend: R - Required; O - Optional; Blank - Not applicable (omit card type)
Entries are of the form R; O; R,O; O,O; R,R
If of the form R or O, the card type can be input for the first Time Period, <u>only</u>
If of the form R,O; O,O; or R,R, the card type can be input for the first Time Period (TP) as specified by the first code <u>and</u> for subsequent Time Periods (if any), according to the second code.

traffic, grades, pedestrian codes for arterial links, number of special use lanes for freeway links, grades, and nominal capacity for freeway links.

The flow characteristic cards are numbered 21, 26, 27, and 34. Turning movement cards (21 for arterials and 26 for freeways) are used to define the turning percentages at each node if the traffic assignment model is not used. The freeway incident specifications card may be used to indicate blocked lanes during the simulation. The freeway parameters card can be used to input a speed-density relationship that the user has developed.

Card types 35, 36, 39, 40, and 41 are the signal characteristics cards. If the signal is a fixed-time controller, the 35 and 36 cards are used to describe the duration of the different phases at the signal and what the signal indicates for each approach to the intersection during each phase. The program does not check the indications on the signal to be sure that the user has not specified movements that will conflict. This allows the user to create signals that may not be realistic but can serve a particular function for the user. All NETFLO Level II nodes must have a signal setting for a fixed-time controller.

Actuated signal controller logic can be simulated for NETFLO Level I nodes with the use of card types 39 through 41. These cards can describe the functions of a single ring controller. All arterial nodes are required to have some sort of "signal" control. Stop and yield signs are permitted, as are nodes with no control, which are indicated by perpetual green indications for each approach to the intersection.

The volume card types 50, 51, and 52 allow the user to specify volumes that enter the network via entry links or from source nodes that can represent mid-block traffic generators, such as shopping malls or parking lots. Load factors can be input to detail the number of passengers in each type of vehicle that is used in the calculations for the "person measures of effectiveness."

Traffic assignment cards are types 175, 176, and 177. They are used to set the parameters for the traffic assignment equations, describe the type of equilibrium desired (either user equilibrium or system optimal), and enter the origin-destination data. If these cards are encountered in the input stream, all previous turning movement information is ignored.

The bus cards can describe station locations, dwell times, route paths, and bus flow data. These are detailed in card types 185 through 189.

The delineation card types 170 and 210 are needed to alert the program about the type of subnetwork next described in the data set and to indicate that all of the data have been read.

Output

The model outputs can be specified by the user, including an echo of the input data, program error and warning messages, traffic assignment results, link statistics, and person measures of effectiveness.

The traffic assignment results are output when the traffic assignment model is used and include the turning movements at each node, in terms of volume and percentage, and the volume of vehicles assigned to the link in vehicles per hour. Spillback, which occurs on a link, is output for each time interval during the initialization period for the assignment model and for each time interval during the simulation.

The cumulative statistics can be output at various specified intervals during the simulation and at the end of the simulation. The statistics for each link include the following:

- vehicle miles traveled on the link,
- vehicle trips made on the link,
- vehicle minutes on the link broken down into the minutes vehicles were moving and minutes delayed,
- minutes per mile,
- time spent on the link per vehicle detailing delay time separately,
- total volume on the link per hour,

- average speed, and
- person miles, trips, and time spent on a FREFLO link.

The output is listed in order of the input data for each link in each subnetwork. A sample output sheet is shown in Figure A.3. The person measures of effectiveness for NETFLO links are output on a separate list from the link statistics.

PROGRAM OPERATION

The CORFLO program begins operation by reading the input data from the input file and creating another input file on a disk to be used during the processing of the subroutines in the program. This is a holdover from the days when input data decks literally consisted of a deck of cards and, once read, the deck could not be entered again. The preprocessor then checks the data for completeness, consistency, and correctness, as described earlier in this appendix. If no fatal errors are found, the traffic assignment model is then run until equilibrium conditions are met. The program next simulates the traffic on the network. The traffic is simulated on each subnetwork for a time interval and the link statistics accumulated. The vehicles are passed to the next subnetwork for the same time interval and simulation is performed for that subnetwork. This is continued for all subnetworks for each time interval until the simulation is completed. The appropriate output is generated at specified points in the simulation by the output processor.

CUMULATIVE FREEWAY STATISTICS AT TIME 16:45: 0

ELAPSED TIME IS 0:30: 0 (1800 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 1800 SECONDS

LINK	VEHICLE MILES	VEHICLE TRIPS	VEHICLE MINUTES MOVE TIME	VEHICLE MINUTES DELAY TIME	VEHICLE MINUTES TOTAL TIME	RATIO MOVE/ TOTAL	MIN./MILE TOTAL TIME	MIN./MILE DELAY TIME	SEC./VEH. TOT. TIME	SEC./VEH. DELAY TIME	AVERAGE VOLUME VPH	AVERAGE SPEED MPH	PERSON MILES	PERSON TRIPS	PERSON-MINUTES TOTAL TIME	PERSON-MINUTES DELAY TIME
(222,7108)	30.4	804	33.2	0.2	33.4	0.99	1.10	0.01	2	0	1607	54.6	39.6	1044	43.2	0.0
(7105, 223)	54.3	273	59.2	4.8	64.0	0.93	1.18	0.09	14	1	545	50.9	70.5	355	82.6	5.6
(223, 224)	4556.4	2673	4905.6	0.0	4905.6	1.00	1.08	0.00	110	0	5346	55.7	5920.5	3473	6328.2	0.0
(224, 225)	522.0	2671	569.4	3.0	572.4	0.99	1.10	0.01	12	0	5341	54.7	678.3	3470	738.4	0.0
(225, 226)	1060.3	2079	1156.6	7.8	1164.4	0.99	1.10	0.01	33	0	4157	54.6	1377.7	2701	1502.1	0.0
(225,7103)	22.2	587	24.3	0.1	24.4	0.99	1.10	0.01	2	0	1174	54.7	28.9	763	31.5	0.0
(7101, 226)	30.2	188	33.0	2.3	35.3	0.93	1.17	0.08	11	0	375	51.3	39.3	244	45.5	2.7
(226, 227)	4261.1	2250	4563.4	0.0	4563.4	1.00	1.07	0.00	121	0	4500	56.0	5536.9	2924	5886.8	0.0
(227, 228)	1649.7	2241	1799.6	7.6	1807.2	1.00	1.10	0.00	48	0	4481	54.8	2143.6	2912	2331.3	0.0
(228, 229)	653.1	1519	712.4	8.9	721.3	0.99	1.10	0.01	28	0	3038	54.3	848.6	1974	930.5	4.8
(228, 238)	27.1	716	29.6	0.4	30.0	0.99	1.10	0.01	2	0	1432	54.3	35.2	931	38.6	0.2
(238, 237)	58.8	1551	64.1	0.3	64.4	0.99	1.10	0.01	2	0	3102	54.7	76.4	2016	83.1	0.0
(8003, 236)	28.0	738	30.5	0.1	30.6	1.00	1.09	0.00	2	0	1476	54.8	36.3	959	39.5	0.0
(236, 229)	12.1	319	13.2	0.0	13.2	1.00	1.09	0.00	2	0	638	54.9	15.7	415	17.0	0.0
(229, 230)	2497.2	1823	2706.5	0.0	2706.5	1.00	1.08	0.00	89	0	3645	55.4	3244.8	2368	3491.4	0.0
(230, 231)	270.4	1802	294.9	10.7	305.6	0.97	1.13	0.04	10	0	3604	53.1	351.3	2342	394.3	11.1
(230, 328)	5.1	18	5.2	0.0	5.2	1.00	1.03	0.00	17	0	35	58.4	6.6	23	6.7	0.0
(231, 232)	255.5	2555	278.7	3.0	281.7	0.99	1.10	0.01	6	0	5109	54.4	332.0	3320	363.4	1.3
(232, 233)	368.4	1939	401.9	3.7	405.6	0.99	1.10	0.01	12	0	3878	54.5	478.7	2520	523.2	1.0
(232, 302)	139.1	612	151.8	1.5	153.2	0.99	1.10	0.01	15	0	1224	54.5	180.8	796	197.7	0.5
(233, 235)	73.4	1938	80.1	0.9	81.0	0.99	1.10	0.01	2	0	3876	54.4	95.4	2519	104.5	0.4
(8002, 301)	1.7	45	1.9	0.2	2.1	0.90	1.21	0.12	2	0	90	49.4	2.2	58	2.7	0.3
(301, 302)	6.8	45	7.4	0.1	7.5	0.99	1.11	0.02	9	0	90	54.2	8.8	58	9.7	0.2
(301, 233)	0.0	0	0.0	0.0	0.0	0.00	0.00	0.00	0	0	0	0.0	0.0	0	0.0	0.0
(302, 303)	65.9	659	71.9	0.5	72.4	0.99	1.10	0.01	6	0	1317	54.6	85.6	856	93.4	0.0
(303, 304)	146.7	638	160.0	4.6	164.6	0.97	1.12	0.03	15	0	1275	53.5	190.6	829	212.4	4.5
(303, 251)	4.1	18	4.5	0.2	4.7	0.95	1.14	0.05	15	0	35	52.5	5.3	23	6.1	0.3
(304, 305)	2238.1	1182	2383.0	0.0	2383.0	1.00	1.06	0.00	120	0	2363	56.4	2908.2	1536	3074.1	0.0
(305, 306)	370.1	1069	403.7	2.0	405.8	0.99	1.10	0.01	22	0	2138	54.7	480.9	1389	523.4	0.0
(305, 330)	8.5	225	9.3	0.2	9.5	0.98	1.12	0.03	2	0	449	53.6	11.1	292	12.3	0.2
(330, 332)	14.8	392	16.2	0.3	16.5	0.98	1.11	0.02	2	0	783	54.0	19.3	509	21.3	0.3
(8004, 331)	10.7	284	11.7	0.0	11.7	1.00	1.09	0.00	2	0	567	55.1	14.0	368	15.1	0.0
(331, 305)	4.3	113	4.6	0.1	4.8	0.97	1.12	0.03	2	0	225	53.6	5.5	146	6.2	0.2
(306, 307)	235.1	1068	256.4	1.6	258.0	0.99	1.10	0.01	14	0	2136	54.7	305.4	1388	332.8	0.0
(306,7301)	0.0	0	0.0	0.0	0.0	0.00	0.00	0.00	0	0	0	0.0	0.0	0	0.0	0.0
(307, 308)	197.2	598	215.1	5.3	220.5	0.98	1.12	0.03	22	0	1195	53.7	256.3	777	284.4	4.9
(307, 310)	44.4	469	48.4	0.7	49.1	0.99	1.11	0.02	6	0	937	54.2	57.7	609	63.3	0.4
(310, 311)	96.4	1018	105.1	0.6	105.8	0.99	1.10	0.01	6	0	2035	54.7	125.2	1323	136.4	0.0
(311, 308)	97.1	570	105.9	0.8	106.7	0.99	1.10	0.01	11	0	1139	54.6	126.2	740	137.7	0.1
(311, 420)	101.7	448	111.0	0.6	111.6	0.99	1.10	0.01	14	0	895	54.7	132.2	582	144.0	0.0
(308, 309)	314.9	1166	343.5	8.6	352.1	0.98	1.12	0.03	18	0	2331	53.7	409.2	1515	454.2	7.9
(309, 312)	52.7	1392	57.5	0.9	58.5	0.98	1.11	0.02	2	0	2784	54.1	68.5	1809	75.4	0.7
(8006, 321)	37.2	981	40.5	0.2	40.8	0.99	1.10	0.01	2	0	1962	54.7	48.3	1275	52.6	0.0
(321, 322)	403.2	720	434.7	0.0	434.7	1.00	1.08	0.00	36	0	1439	55.7	523.9	935	560.8	0.0
(321, 319)	45.3	266	48.9	0.0	48.9	1.00	1.08	0.00	11	0	531	55.6	58.8	345	63.1	0.0

Figure A.3. Sample Output of Cumulative Freeway Studies

APPENDIX REFERENCES

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